The Dynamics of Energy/Socio-Economic Interaction.

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'The current crisis, therefore, is not just a crisis of individuals, governments or social institution; it is a transition of planetary dimensions. As individuals, as a society, as a civilization, and as a planetary ecosystem, we are reaching the turning point.'

Fritjof Capra.

'The transition from a colonizing to a climactic mode of existence is the most profound change our species will ever have to make. That crossroads is now before us.'

Jeremy Rifkin.

Abstract.

A Dynamic Energy Systems Model of world energy usage has been produced in this report. It is based on the storages, flows, utilization and dissipation of energy of man-made society at the global level. It models the interaction of energy supply sectors, in the form of fossil fuel stock resources, an environmental flow source, and their refining industries, with the socio-economic sector of society, consisting of an infrastructure which manufactures, distributes and consumes goods and services.

The model simulates a new form of primary energy (coal, oil or gas) penetrating the existing energy market at a new point in time. Each new form of energy, or energy sector, is externally characterised by 3 parameters: Availability, Accessibility and date of inception (Inceptdate).

The nature of the model is explained, and results from the computer simulation of the model, showing the market shares of primary energy sectors over time, and other related data, are presented.

Specifically, the results show that a previously discarded energy source may be 'revisited', that modelling 2 energy stock resources of widely differing Accessibility creates a highly disruptive energy 'spike', and that the behaviour pattern (either aggressive or cooperative) of 2 energy stock sectors is dependent on the date of inception.

Acknowledgements.

I would like to sincerely thank Dr. P. S. Bodger, my supervisor, for all his support and guidance throughout the course of our project. I recall when many a conversation between Dr. Bodger and myself increased my personal awareness, and expanded my horizons. It is indeed a priviledge to have shared ideas with Dr. Bodger, and I am sure that because of this, I have grown as a person.

Similarly, I am indebted to Mr. J.T Baines of the Resource Management Centre for his help and insight of energy modelling.

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Finally, I wish to acknowledge the technical assistance given to me by other postgraduate students, and staff, and a special thanks to Ross Murch. These people greatly eased the implementation of ideas into practicalities.

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Key.

The key shown below is a guide to the many Figures used throughout this report. Some Figures show only 1 energy sector, others show 2, 3, 4 and 5 sectors. Where there are 1, 2 and 3 sectors, the key should be taken to mean the first, second or third sector, and if labels are relevant to these sectors, then they will be given in the text. Otherwise, with 4 and 5 sectors, the key refers to the sectors in the order of Biomass (B), Coal (C), Oil (O), Gas (G), and Nuclear (N) for the 5th sector.

First sector

Second sector

Third sector

Fouth sector

Fifth sector

Chapter 1

Introduction.

Many models used for energy and economic forecasting are built around man - made variables such as price, GDP, exchange rates, interest rates, capital et cetera, representing real goods and services and their interactions. While such variables may appear useful for creating energy/economic scenarios, they may be artificially controlled or regulated. An alternative energy analysis model approach has its roots in the energy basis for all physical activity [1]. As such, there is no hint of any cosmetic approach, because energy is invariant over time. A joule of energy today is the same as a joule 100 years ago; or 1000 years ago. A model based on energy values is based on physical reality.

Cesare Marchetti[2] has shown a strong link between the introduction, maximum market penetrations, and prices of new primary energies, and innovation waves. He suggests that economic features may be the expression of deeper 'physical' phenomena related to the basic working of society, and thus become predictable up to a point through an abstract and non-economic analysis. This work formed the basis of further investigations into the behaviour of energy/society interaction by associating the sequence of the substitutions of the primary energies with the trend in thermodynamic availability and accessibility of the energy resources[3]. Additional work[4] established similarities in the spectral graphs of world primary energy consumption and world industrial production, and concluded that the former contained the independent nature of the world energy/economic system. These investigations have succeeded in producing a computer simulation of a dynamic energy systems model, based on energy storages, flows, utilization and dissipation, incorporating both energy sectors and a socio - economic, or producer - consumer sector. It is a dynamic energy model, which simulates a new form of primary energy (coal, oil, or gas) penetrating the existing energy market at a new point in time. Each form of energy, or energy sector, is externally characterised by three parameters: Availability, Accessibility, and date of inception, (Inceptdate). These parameters are explained more fully in Chapter 3.

This report explains the nature of the dynamic energy systems model in both qualitative and quantitative terms, presenting graphical results of the computer simulation runs. But it begins with a short comparison between economics and energy analysis, emphasizing the reasoning behind the perceived superiority of energy analysis. Then, Chapter 3, 'Explanation of the Model - An Outline of How it Works', attempts to explain in a qualitative fashion, the 3 external energy supply parameters, and overview how the energy sectors and the socio-economic sector function. Chapter 4, 'Equations used in the Model', provides a quantitative description of the flows and storages used in the computer simulation.

The chapters following these explore the changes in pattern of the basic market share graph under varying conditions of external parameters. Other supporting graphs are presented where useful. The chapters begin with a specific treatment of 1 energy stock sector, then 2 energy stock resources in competition, including both an inception time differential, and equal Inceptdates. Attention is drawn to the significance of the remarkable results obtained for 2 stock sectors. General results of 2 stock sectors with an inception time differential, including the effect of changing the Availability, Accessibility and Inceptdate parameters, are also presented. Observations from a simulation of 2 sectors, composed of 1 flow source and 1 stock resource in competition are noted, followed by 3 sectors, consisting of 1 flow source and 2 stock sectors.

Following this, the accomplishment of replicating the historical data of primary energy forms over time, as compiled by Marchetti, is described. The effect of perturbating internal model parameters is described, as is the necessity to change the inception level from 1% to 0.1%.

Finally, these 4 sectors are augmented by a 5th sector, which is labelled the nuclear sector, and the results observed.

Chapter 12 discusses aspects of the model which may benefit from a restructuring. This restructuring is a suggestion to refine the model for further work.

I have entitled Chapter 13 'The metaphysical importance of Energy'. Extracts are used from the works of two highly respected authors to emphasize that energy is fundamental to society, yet it is partly because of the attitude of our society toward energy that we are facing an uncertain and dangerous future.

In the graphs which follow, the parameters are given in the appendix for the Inceptdate, Availability and Accessibility of each of the sectors, which themselves are abbreviated to B (biomass, or wood), C (coal), O (oil) and G (gas). The 5th sector is designated N (nuclear).

Chapter 2

Economics and Energy Analysis.

Economics is a distribution mechanism. Its dynamics are described with reference to an assumed equilibrium state that could continue 'ad - infinitum' if it were not disturbed by changes in production technology or by changes in the pattern of consumer preference and expectation.

From an economic perspective, system dynamics are interpreted in relation to a range of *internal* stocks and flows - capital, labour, raw materials, and goods and services produced. Similarly, the factors which influence and ultimately constrain the dynamics of the economic process are *internal* parameters - marginal productivity of factors, prices of goods and prices of factors, profitability, liquidity, balance of payments, inflation, deficit before borrowing, return on investment (ROI), discount rates, et cetera.

A preoccupation with adjusting to constraints that are *internal* to the economic process ignores the essential relationship between process and environment. The absolute outer limits to dynamic, physical activity are defined by energy supply. No social or economic utility can be generated without the consumption of available energy, and its consequent degradation. In other words, *the dynamics of the economic process are ultimately constrained by the availability of energy in the environment, and its accessibility for economic consumption.*

From an energy perspective of economic activity, physical, and therefore economic activity depends upon the availability and accessibility of energy resources. Growth results from the building of an economic infrastructure which increases the economy's capacity to exploit the energy resources from the environment. This infrastructure, for capturing, transforming and distributing energy in a complex of desired usable forms, is only possible because of prior resource utilization[5].

Because the common denominator is covered by the laws of nature, energy analysis may offer a more responsive as well as a more holistic approach to planning and policy making. Being grounded in the universal laws of nature, the analysis technique is able to treat the system of concern as the 'combined economy of man and nature', rather than as two separate systems with recognised but poorly understood linkages. In energy analysis, the use of energy and time (i.e. energy flow) to generate work is seen as the linking mechanism between the natural environment system and the human system, thereby setting the stage for a unified, more complete analysis of the combined system[1].

Energy Analysis (EA) has a frame of reference that can be considered as absolute (since it relates to concepts of mass and absolute zero temperature), whereas that of economics is relative[1]. Energy Analysis may be more realistic than economics, but is it acceptable for forecasting purposes ? Appendix A, 'A Note on Forecasting', overviews some aspects of forecasting and discusses these with repect to Energy Analysis.

The Energy Analysis literature on dynamic systems modelling is dominated by the activities of Howard Odum, his co-workers and students from Florida.

Odum states: 'Energy Analysis is the modelling of systems accompanied by the evaluation of energy flows inherent in the system. It includes a synthesis of parts into whole patterns where energy flow is used as the common unit of measure among parts. In practice, energy analysis starts with a diagram of important flows, structures, storages and process interactions. Such a diagram is accompanied by universal evaluation and appropriate tabular documentation. This evaluated energy diagram shows simultaneously, energy balances, energy transformations, kinetics, material flows, information flows, and work transformations.'

'From this basic energy diagram, various aggregate calculations and simulations can be carried out. These result in an evaluation of the role parts of the systems play in maintaining the vitality of the whole. Energy Analysis shows common characteristics among systems of different types and suggests new energy concepts.'

'Central to this method of energy analysis is the use of energy symbols and energy circuit language. The symbols allow systems to be diagramatically represented.'

Our dynamic energy systems model uses the symbols from Odum's 'Systems Ecology - An Introduction.'[6]

2.1 Conflicts between Energetic and Economic perspectives.

There are many conflicts between these two paradigms. Probably neither paradigm is totally correct, but each is complementary to the other. But it is increasingly apparent that an energy perspective is far more realistic.

A key conflict is that of the meaning of energy, and its conservation. Energy analysts are concerned with the thermodynamic availability of a quantity of energy. And although energy itself is conserved, the thermodynamic availability is not conserved, because energy is always being consumed (and therefore the thermodynamic availability of energy is always decreasing). This is, in the opinion of the author, the fundamental difference between an energy analyst's, and an economist's, way of thinking.

If one thinks in terms of thermodynamic availability, or entropy, then one automatically realises the inherent irreversibilities, and limitations, of the real world. But if one thinks in terms of energy, and its conservation law, then one sees a physical picture of the world as being analogous, on the surface, to the economic view, with its accounting balance.

Chapter 3

Explanation of the Model - An Outline of How it Works.

The model consists of energy sectors interacting with a socio - economic, or producer - consumer sector.

Energy is supplied by the energy sectors to the socio - economic sector, where it is transformed, consumed and partially fed back to the energy sectors. Each form of primary energy, or energy sector, is externally characterised by three parameters: Availability, Accessibility, and date of inception, (Inceptdate).

The Availability of energy in any sector represents how much of an energy resource stock is potentially there to be utilised and converted into useful energy by an energy refining sector. For instance, in the case of oil, it is a quantitative measure representing how much oil is thought to exist (but not necessarily proven) at the time oil enters the energy market. Applying the concept of Availability to the flow source, it represents the flow from the sun which is capable of being tapped.

The Accessibility of energy in any sector represents how much effort, in energy terms, is required to actually get hold of that stock and convert it into useful energy, per unit of useful energy finally delivered. This is termed the energy yield ratio. For example, oil may be more expensive (in energy terms) to bring to the surface and refine than wood, but oil also releases a greater amount of useful energy. The Accessibility of oil may be greater or less than that of wood, depending on the ratio of energy yield to energy expenditure for oil, and that same ratio for wood. Whichever ratio is the higher determines which fuel is more accessible. Generally, oil is more accessible than wood (given this interpretation of Accessibility).

The Inceptdate of an energy sector is the year in which the new sector penetrates the energy market at a given level.

3.1 The Socio-Economic Sector.

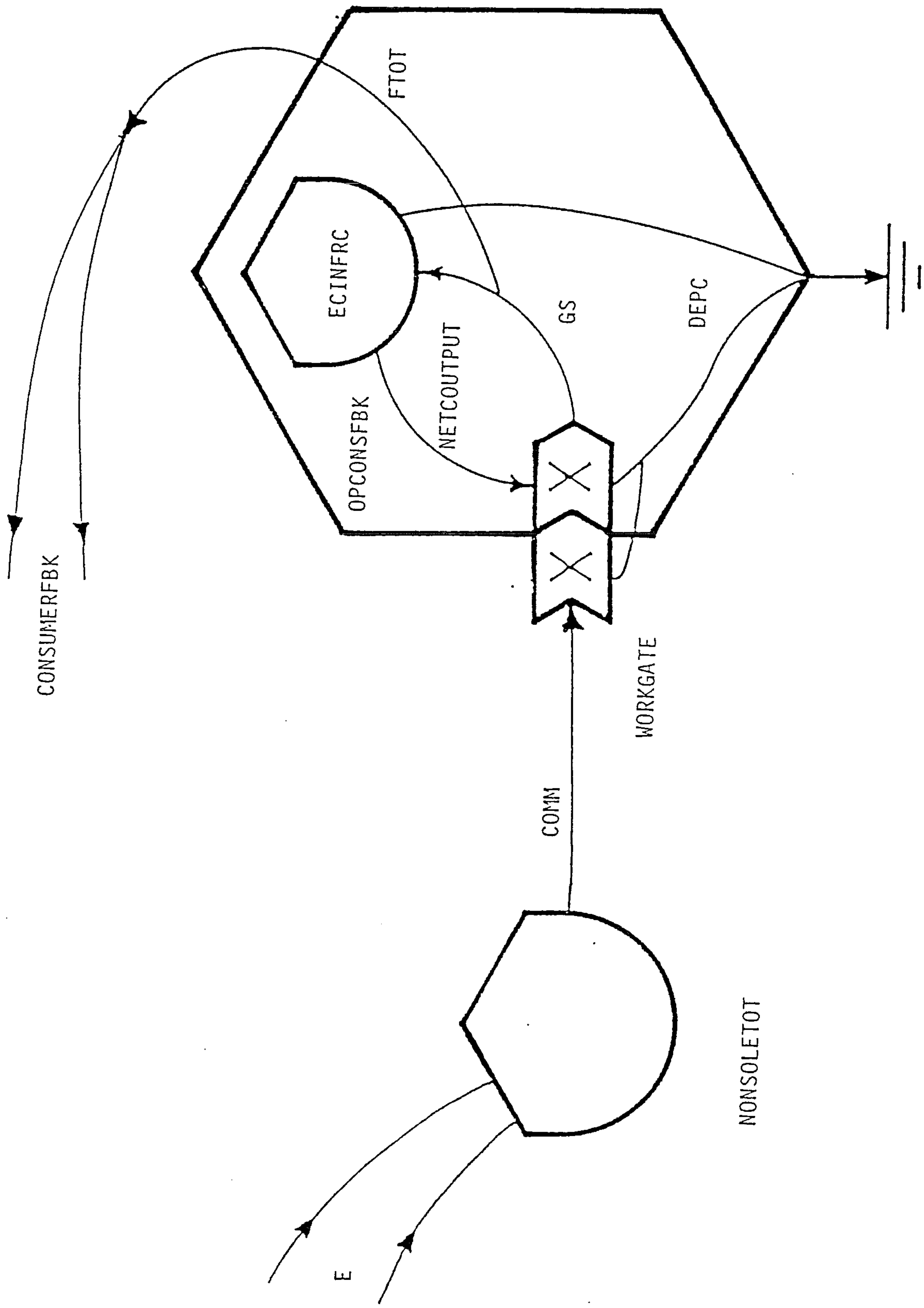
The socio - economic sector, shown in Figure 1, consumes energy to grow. It uses energy in the production of all goods and services, and it feeds back some of this energy, embodied in the specific goods and services necessary for the energy sectors themselves, in order that they may continue to supply energy to the socio - economic sector.

A 'workgate' is a production function in which energy inputs interact to produce output goods and services. Inputs include both direct energy (ie. the energy output from the energy refining industries) and embodied energy in the form of goods and services fed back from the economic infrastructure, OPCONSFBK. The output of the workgate is labelled 'GS' because it is split into two quantities. NETCOUTPUT, the net consumer sector output, is fed into the economic infrastructure of the sector, ECINFRC, while FTOT, the total feedback from the consumer sector, is fed back to the energy sectors, shared in direct proportion to the accessibility and energy output of each sector, relative to competing sectors, CONSUMERFBK.

The phrase 'economic infrastructure' means the entire man - made physical domain within the economic process. As such, it includes all man - made physical structures, eg. buildings, transport and communication networks, and technological hardware, as well as the accumulation of skills, experience, knowledge and culture. It includes the stockpiles of partially or fully processed environmental resources eg. diesel, manufactured fertilizers, and so forth which are passing through the economic process. It is the accumulation of physical capital that is involved in the activity of the economic process, that is continuously being maintained, replaced and added to [5]. An output from the economic infrastructure, OPCONSFBK, is then fed back to the workgate, enabling it to function effectively, ie. the workgate requires energy to be functional.

As a result of the processes of both the workgate transformation and the economic infrastructure consumption and transformation, a degraded form

FIGURE 1 - THE SOCIO-ECONOMIC SECTOR



of energy, of higher entropy, is produced. This energy delivers no further work, and crosses the boundary of the socio - economic sector as heat. It is labelled DEPC for depreciation of the consumer sector, and is given the earthing symbol. It is a recognition of the fundamental degradation of energy in any physical processes as embodied in the Second Law of Thermodynamics.

3.2 The Energy Supply Sector.

The energy supply sectors (Figure 2) are composed of Environmental Stock Reserves (ESR), such as fossil fuels, which are limited in total amount available, and an Environmental Flow Source (EFS), being solar radiation and its derivatives which are practically unlimited in total amount but strictly limited in rate of usage, due to the finite flow rate. Each sector has its own energy refining industry. The ESR's are so named because they are limited in Availability and are generally pumped, mined, excavated or otherwise accessed from the protection of the environment. An example is coal, which lies in the earth - it must be mined or excavated before it can be used. The raw resource is converted into useful energy (be it electrical energy via a coal fired boiler and generator in a power station, or heat simply by burning as a fuel), then delivered to the socio - economic sector.

An EFS, or renewable solar energy, takes many forms. It is available as wood in forested areas, it can be produced as a liquid or a gaseous fuel such as alcohol or methane from plant products in agricultural areas, it is present as potential hydro-electric power in mountainous regions, and as wind power in wind swept areas. The turbines in hydro-electric power stations are driven by the kinetic energy of the falling water. This water is later absorbed by the atmosphere and then falls as rain, trickling down into reservoirs and dams, where its potential energy is again transformed to kinetic, and the cycle repeats. The cycle, in turn, is sustained by the sun's radiation. The wind, historically used for powering sails and driving windmills, is an airflow caused by thermal air currents, heated by the sun. Solar energy can be transformed in sunny areas into electricity by photovoltaic cells, and collected directly as heat almost anywhere.

The flow of energy labelled DIRECT, is derived from the sun's radiation and captured on and around our planet.

The central difference between the Flow From the Environmental Flow Source, FFEFS, and DIRECT, is that the former is generally managed, while the latter is generally unmanaged. Examples of a FFEFS are forestry, which is harvested for timber, agriculture and horticulture, where crops are managed for consumption, and hydro dams for power generation. Examples of the DIRECT component include unmanaged forestry, plant life, brush and

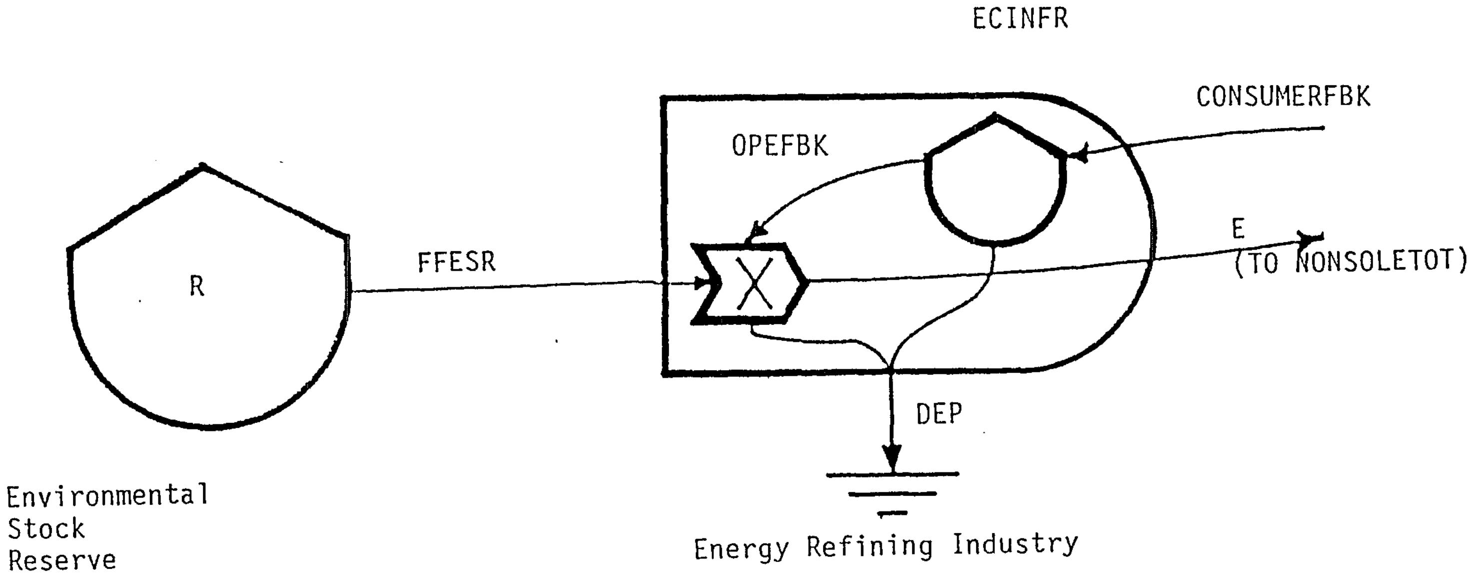


FIGURE 2 - THE ENERGY SUPPLY SECTOR

vegetation:in fact, most natural things.

Each refining industry has its own economic infrastructure, workgate and depreciation, similar to that of the socio - economic sector. However, the workgate output is not fed back into the refining sector economic infrastructure (the latter does not directly create goods and services for its own consumption); it is instead all delivered to the socio - economic sector. The sectoral infrastructures receive their inputs from the output of the workgate of the socio - economic sector, CONSUMERFBK, as previously outlined.

3.3 The Energy/Socio-Economic System Model.

The outputs from each energy sector are aggregated for simplicity into a common supply to the socio - economic sector. The entire system model is shown in Figure 3.

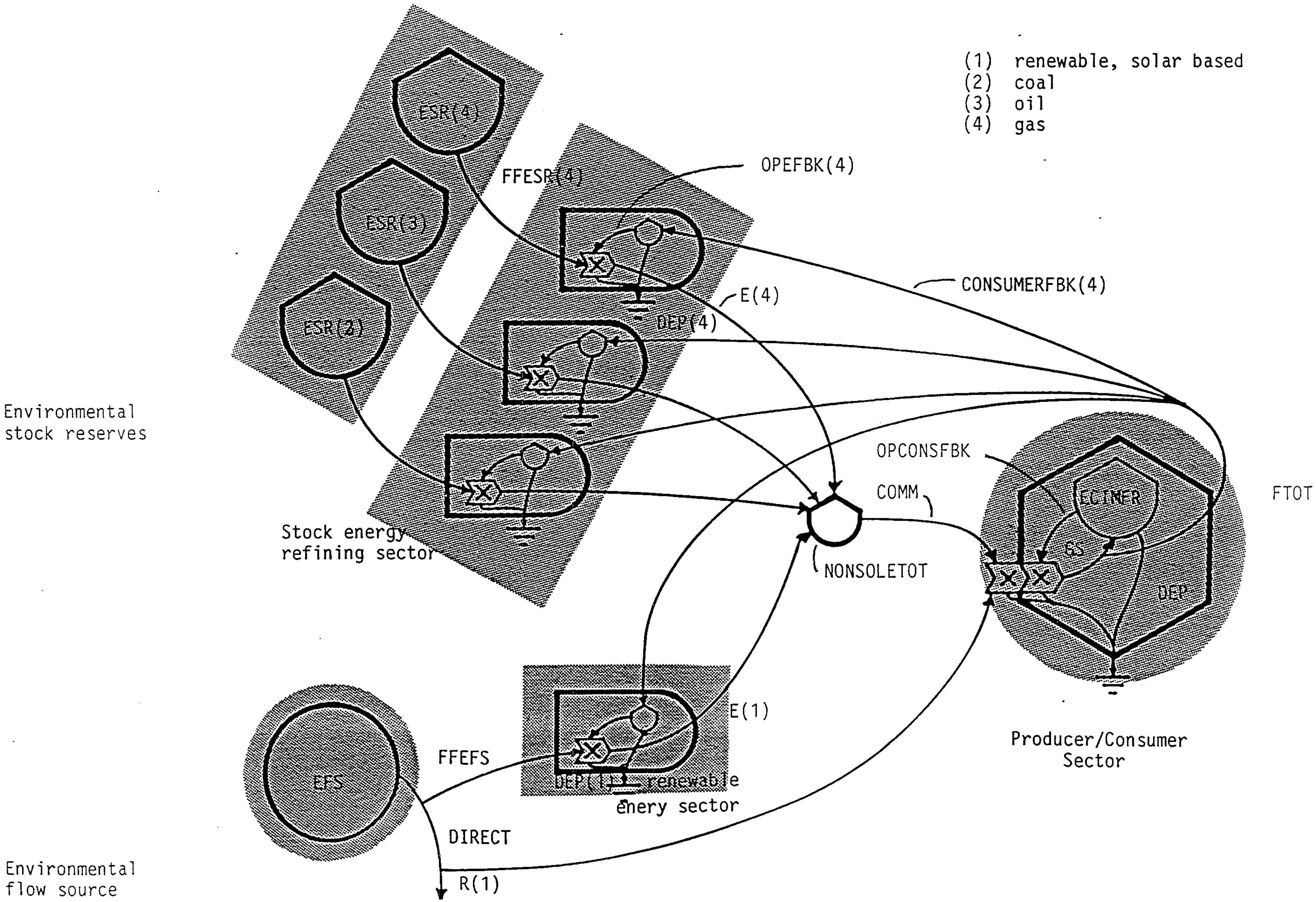


FIGURE 3 - THE TOTAL SYSTEM MODEL

Chapter 4

Equations used in the model.

This chapter describes the variables and equations used in the program developed to represent the energy/socio-economic system discussed in Chapter 3. Because of the complex nature of our model, ie. a network of energy storage, transforming and dissipative elements; coupled by both feedforward and feedback paths, it is impossible to a priori set initial values of variables so that case runs yield realistic results. These are just not known. Rather, it is the results themselves which must be used to select the initial values so that if time plots of selected outputs are in accord with reality, then the selected values are assumed to be the correct ones. There is no alternative. We have thus chosen our initial values of variables such that the initial patterns of market share penetrations and declines resemble those of the interactions of world primary energy consumptions of Marchetti[2].

The model is subsequently only perturbed when new energy forms are introduced, or the external parameters of Availability, Accessibility and Inceptdate are changed to observe the consequences.

4.1 The Energy Sector.

The flows into and out of an energy refining industry are governed by the interaction between the size of the remaining stock resource, R(v), and the accumulated effort to access the resource, ECINFR(v).

1(a). OPEFBK(v) = E(v)/ACCESSORIGINAL(v)
1(b). OPEFBK(v) = H(v) $\times$ ECINFR(v) $\times$ R(v)

The operational energy feedback OPEFBK(v) is provided by the energy sector infrastructure to the workgate. It initially equals the amount of energy produced by the sector, E(v), divided by the original accessibility of the sector, ACCESSORIGINAL(v) (equation 1 (a)).

Iteratively (equation 1(b)), the operational energy feedback equals a constant, H(v), times the infrastructure size ECINFR(v), times the remaining stock resource for that sector, R(v). The feedback is intuitively proportional to the infrastructure, but is also affected by the driving force behind the fuel flow from the untapped stock. This driving force is parametrised by R(v) which can be thought of as the amount of water in a water storage tank with a pipe at the bottom. If R(v) is large, then there is more pressure to force out the water from the tank, than if R(v) is small. Hence the feedback is affected by the flow rate of fuel to the energy sector; this flow rate is directly affected by the pressure behind it, which is R(v).

2(a). E(v) = 0.001/0.999 $\times$ COMM
2(b). E(v) = G(v) $\times$ ECINFR(v) $\times$ R(v)
2(c). DIRECT = kk $\times$ NONSOLETOT $\times$ ECINFRC $\times$ EFS/(1 + kk $\times$ NONSOLETOT $\times$ ECINFRC + k(1) $\times$ ECINFR(1))

For a new energy sector, its energy output is initially set at 0.1% of the total energy output of all other energy sectors from the previous iteration (equation 2(a)). This is done to give the new sector an energy value relative to the other sectors at that time. The Figure of 1.0% was chosen originally, but was found to give undesirable cusps because it acted like a step input. The Figure was later reduced to 0.1%, producing far smoother curves.

Iteratively, the energy produced by the refining sector (equation 2 (b)) can be thought of as the product of a constant, G(v), the size of the sector infrastructure, ECINFR(v), and the driving force or pressure of the fuel reservoir, R(v). Thus the energy produced by the workgate is dependent on two factors: the fuel from the stock reserves and the feedback provided by the energy sector economic infrastructure.

Equation 2(c) is the iterative equation for the quantity of energy, DIRECT, which is derived from the sun's radiation and captured on and around our planet. The mathematical derivation of DIRECT can be found in Appendix (c).

3(a). $\mathrm{FFESR(v)} = 1.1 \times \mathrm{E(v)}$

3(b). $\mathrm{FFESR(v)} = \mathrm{K(v)} \times \mathrm{ECINFR(v)} \times \mathrm{R(v)}$

3(c). $\mathrm{FFEFS} = \mathrm{k(1)} \times \mathrm{ECINFR(1)} \times \mathrm{EFS} \,/(1 + \mathrm{kk} \times \mathrm{NONSOLETOT} \times \mathrm{ECINFRC} + \mathrm{k(1)} \times \mathrm{ECINFR(1)})$

Equation 3(a) is an initial condition equation for a new energy sector to determine its flow of fuel from the stock reserve to the energy refining industry. FFESR, the Flow From the Environmental Stock Reserve (to the refining industry) is set at 1.1 times the initial energy output of that sector. More energy (fuel) goes into that sector than comes out. The difference is a combination of the feedback from the sector's own economic infrastructure and the energy lost to the outside environment as that which is no longer useful (heat).

Equation 3(b) is the iterative equation for FFESR. It states that the FFESR is a product of a constant, K(v), the economic infrastructure of that sector, ECINFR(v), and the remaining untapped stock resource for that sector, R(v). The greater the untapped fuel reserve and the greater the economic infrastructure of the energy sector, then the greater will be the flow of fuel from the reserve to the refining industry. This is because the economic infrastructure supplies the workgate with the materials it needs (eg. mining equipment, transport, personnel etc.). The more the workgate has at its disposal, the more fuel it can access. And more fuel will be accessed if it is in plentiful supply, as opposed to being a scarce fuel. Hence the dependence on R(v).

Equation 3(c) is the iterative equation for the Flow From the Environmental Flow Source (FFEFS) to its refining industry. This equation is governed not only by its own infrastructure, but also by the socio-economic infrastructure, and NONSOLETOT. The derivation of Equation 3(c) can be found in Appendix (c).

4(a). $\mathrm{ECINFR(v)} = 5 \times \mathrm{E(v)}$

4(b). ECINFR(v) = ECINFR(v) + NEWINFRENERGY(v)

The economic infrastructure is initialised in equation 4(a) as being 5 times the initial energy output of that energy sector. Iteratively (equation 4(b)), it is a running total of the previous value of ECINFR(v), plus the present iteration value of the new energy sector infrastructure, NEWINFRENERGY(v). This new infrastructure may be either positive or negative, depending on whether the sector is growing or decaying.

5. NEWINFRENERGY(v) = CONSUMERFBK(v) - OPEFBK(v) - DEP(v)

Equation 5 is a simple net sum gain equation, where the net change is the balance of the flows going in, with those coming out. The new infrastructure of the energy sector, NEWINFRENERGY(v), equals the consumer feedback from the socio - economic sector, CONSUMERFBK(v), less the operational energy sector feedback, OPEFBK(v), less the depreciation from the infrastructure, DEP(v). That is, it equals the input from the socio - economic sector, less the outputs to the workgate and the environment. This is the growth or decline of the infrastructure.

6(a). DEP(v) = $0.22 \times$ ECINFR(v)
6(b). DEP(v) = L(v) $\times$ ECINFR(v)

The depreciation of an energy sector, DEP(v), is initialised at 22% of its economic infrastructure (equation 6(a)). Iteratively, it is a constant, L(v), times the economic infrastructure of the energy sector. It would be expected that the depreciation of a process, that is, the waste energy produced by a process, is proportional to the size of the process itself, for a given efficiency.

7(a). COMM0 = $\sum$ E(v)
7(b). NONSOLARSHARE(v) = E(v)/COMM0

The non - solar energy shares for each sector, NONSOLARSHARE(v), are given by the amount of energy each sector produces, E(v), divided by the sum of the energy from all the energy sectors. This is COMM0, or the sum of E(v).

8. F0(v) = NONSOLARSHARE/(1-NONSOLARSHARE(v))

Instead of looking at market energy share over time simply as a percentage, it is helpful, especially when working with curves of a logistic nature, to create a function of the form F(x) = x/(1-x), and plot the log of F(x) over time. This was the presentation used by Marchetti [2].

9. ACCESS(v) = E(v)/OPEFBK(v)

The accessibility of an energy sector, ACCESS(v), is the energy output, E(v), divided by the operational energy feedback, OPEFBK(v). It is the ratio of energy out, to energy in (to the energy sector workgate). The accessibility is a measure of the energy required to access a fuel, but also accounts for the energy the fuel will give out when used. It is the energy one reaps, divided by the energy one sows in order to reap.

10. ACCESSAVERAGE = $\sum$ (ACCESS(v)$\times$NONSOLARSHARE(v))

The 'average accessibility' is a consumption related weighted average of the accessibility of all energy sectors. NONSOLARSHARE(v) is always less than or equal to 1, and the average accessibility is influenced by the degree of market share each sector owns. The average accessibility is a compound of the accessibility and market share of each energy sector. It is summed for all energy sectors.

11. QUOTA(v) = ACCESS(v) $\times$ NONSOLARSHARE(v)/ACCESSAVERAGE

The quota of feedback goods and services from the socio - economic sector workgate to each energy sector is given by each sector's accessibility, its market share, and the average accessibility of all the energy sectors. That is, the sector with the higher accessibility and market share, relative to another sector, will receive a greater percentage, or quota, of the feedback from the socio - economic sector.

12. NEWINFRTOT = $\sum$ NEWINFRENERGY(v)

The total new infrastructure in the energy supply sectors, NEWINFR-TOT, is the sum of the individual new infrastructures in the energy supply sectors.

13. NONSOLETOT = NONSOLETOT + COMM - COMM0

The total non - solar energy storage, NONSOLETOT, is a storage tank for the sum of the energy sector outputs, COMM0. Its initial value is arbitrarily above a certain level. It does not affect the energy flow into the socio - economic sector. Its purpose is to act as a damping mechanism to slow down the growth of the system dynamics, regulating the model from exponentially building up and driving itself into overflow. The larger the initial value of NONSOLETOT, the greater the damping effect. COMM0 is used as an energy flow. COMM is the value of COMM0 from the previous iteration. The physical parallel of this modelled storage is the multitude of fuel depots, consisting of containing vessels to accumulate and supply the needs of society and its associated industries. Because these depots store a large quantity of fuel compared to the amount used daily, they have a buffering effect on any fluctuation in supply. They desensitize the user to supply fluctuations.

14(a). R(v) = R(v) - FFESR(v)
14(b). R(1) = EFS - DIRECT - FFEFS

The remaining energy stock is the previous stock level less the present fuel flow from the stock reserve (equation 14(a)).

Equation 14(b) indicates that the remaining untapped solar energy flow, R(1), is the energy emanating from the source, EFS, less the DIRECT component directed toward the earth, less the tapped flow, FFEFS.

4.2 The Socio-Economic Sector.

The flows in the socio - economic sector are governed by the 'pressure' of the incoming energy, NONSOLETOT, and the accumulated effort to use it, ECINFRC.

15. OPCONSFBK = HH $\times$ NONSOLETOT $\times$ ECINFRC

The operating consumer feedback, OPCONSFBK, is the feedback in the socio - economic sector from the economic infrastructure to the workgate. This is given by the product of a constant, HH, the economic infrastructure of the socio - economic sector, ECINFRC, and the total non - solar energy output storage from the energy sectors into the workgate, NONSOLETOT. This is similar in structure to equation 1(b), the operational energy feedback for an energy sector.

16. DEPC = LL $\times$ ECINFRC

The depreciation of the consumer, or socio - economic sector, DEPC, is a constant, LL, times the magnitude of its economic infrastructure, ECINFRC. The depreciation is directly proportional to the size of the infrastructure.

17. GS = GG $\times$ NONSOLETOT $\times$ ECINFRC

The gross output from the workgate of the consumer sector, GS, is the product of a constant, GG, the economic infrastructure, ECINFRC, and the non - solar energy output storage from both the stock sectors, NONSOLETOT. It may be thought of as another constant times the operating consumer feedback, OPCONSFBK (equation (16)).

18. FTOT = 0.5 $\times$ GS/ACCESSAVERAGE

The total output from the consumer sector to the energy supply sectors, FTOT, is given by the gross output from the workgate of the consumer sector, GS, times a constant (0.5), divided by the average accessibility of all the energy sectors, ACCESSAVERAGE. Some of GS is diverted to FTOT, the rest of GS is fed into the economic infrastructure. Therefore, FTOT must necessarily be smaller than GS, and acts as a negative feedback system, or a moderator, for the energy supply sectors, via ACCESSAVERAGE. FTOT is proportional to the inverse of ACCESSAVERAGE, so if the average accessibility of the energy sectors is climbing, then FTOT will act to reduce the absolute amount of feedback they will receive, and vice versa.

19. NETCOUTPUT = GS - FTOT

The net consumer sector output, NETCOUTPUT, is the gross output, GS, less the feedback to the energy sectors, FTOT. NETCOUTPUT is fed into the consumer sector infrastructure.

20. NEWINFRCONSUMER = NETCOUTPUT - OPCONSFBK - DEPC

This is another net sum gain type of equation. The new infrastructure in the consumer sector is the net gain or loss of the infrastructure, that is, the sum of the net consumer output feeding into it, NETCOUTPUT, less the operating consumer feedback to the workgate, OPCONSFBK, less the depreciation, DEPC.

21. CONSUMERFBK(v) = QUOTA(v) $\times$ FTOT

The absolute consumer sector feedback to each of the energy sectors, CONSUMERFBK, equals the quota each sector commands, QUOTA(v), times the total amount of feedback available, FTOT. The quota determines the relative feedbacks, while the total amount available determines the absolute feedbacks to the energy sectors.

22. ECINFRC = ECINFRC + NEWINFRCONSUMER

The present economic infrastructure of the consumer sector is the previous infrastructure plus the new infrastructure, NEWINFRCONSUMER, which may be either positive or negative.

4.3 Constants.

The constants used in the previous equations are set according to the initial values of the variables they involve. The form of the equations is a rearrangement of the equations in the set (1) to (22) in which they are involved.

23. HH = OPCONSFBK/(NONSOLETOT $\times$ ECINFRC)

24. LL = DEPC/ECINFRC

25. GG = GS/(NONSOLETOT $\times$ ECINFRC)

26. K(v) = FFESR(v)/(ECINFR(v) $\times$ R(v))

27. H(v) = OPEFBK(v)/(ECINFR(v) $\times$ R(v))

28. L(v) = DEP(v)/ECINFR(v)

29. G(v) = E(v)/(ECINFR(v) $\times$ R(v))

Chapter 5

Results of a single sector, and a double sector with the same Inceptdates.

First one energy sector, and then two sectors together, are modelled to interact with a socio - economic sector, itself modelled by energetic parameters. Results are presented showing the market share of the energy supply sectors, the depletion of energy resources, and the growth and decline of sector infrastructures.

5.1 Single sector

The Availability of a single energy supply sector was arbitrarily set to 8000 energy units. The Accessibility or energy yield ratio was set to 5 and fixed at this value over time. Thus the possibility of an improved Accessibility over time due to increased technological efficiency is considered to be offset by that technology having to be applied to more scarce resources; the easiest to recover having been utilized first. The flows associated with this sector supplying energy to the socio - economic sector are presented in this section.

5.1.1 The Energy Sector.

The infrastructure of the energy refining industry, Figure 4, shows a gradual buildup, caused by the very small but positive addition to the infrastructure for each iteration. However, the addition to this infrastructure, is actually decreasing with time, (although it is still positive) as shown in Figure 5.

The energy yield, shown in Figure 6 (and similarly the operational energy feedback, and the flow from the environmental stock reserve) decreases gradually. Even though the energy yield is decreasing, there is a continual addition via the consumerfeedback of Figure 7 to the energy infrastructure from the socio - economic sector. The overall result is an infrastructure of increasing size, but producing less and less energy. The reason for these trends hinges on the amount of environmental stock resource, as shown in Figure 8. The stock decreases, as governed by the energy flow from the stock reserve to the energy refining industry. The consumerfeedback increases with time and this acts to increase the size of the energy infrastructure. But the operational energy feedback coming out of the infrastructure decreases, as it is proportional to both the infrastructure *and* the remaining stock reserve. The net multiplicative change in remaining stock and infrastructure is a decrease. Since the infrastructure increases in size, the remaining fuel stock decreases faster than this increase, hence decreasing the operational energy feedback with time, and the infrastructure grows while the sector is producing less energy. The flow from the environmental stock reserve (FFESR) also decreases non-linearly, because it is governed by the same variables as the operational energy feedback.

Hence the energy sector output and flows (except the consumerfeedback) decrease with time due to the dwindling quantity of the nonrenewable stock reserve. However, it should be observed that the energy returned to the environment in a low grade non-usable form (depreciation) increases in association with the increased infrastructure of the energy refining industry.

5.1.2 The Socio - Economic Sector.

Like the energy sector, the infrastructure of the socio - economic sector, Figure 9, shows a gradual buildup because of the very small but positive addition of the new infrastructure from each iteration, Figure 10. The consumer flows are dependent to a large extent on the infrastructure and the energy storage tank (NONSOLETOT). But the energy storage tank acts as

FIGURE 4 - ENERGY REFINING INDUSTRY INFRASTRUCTURES

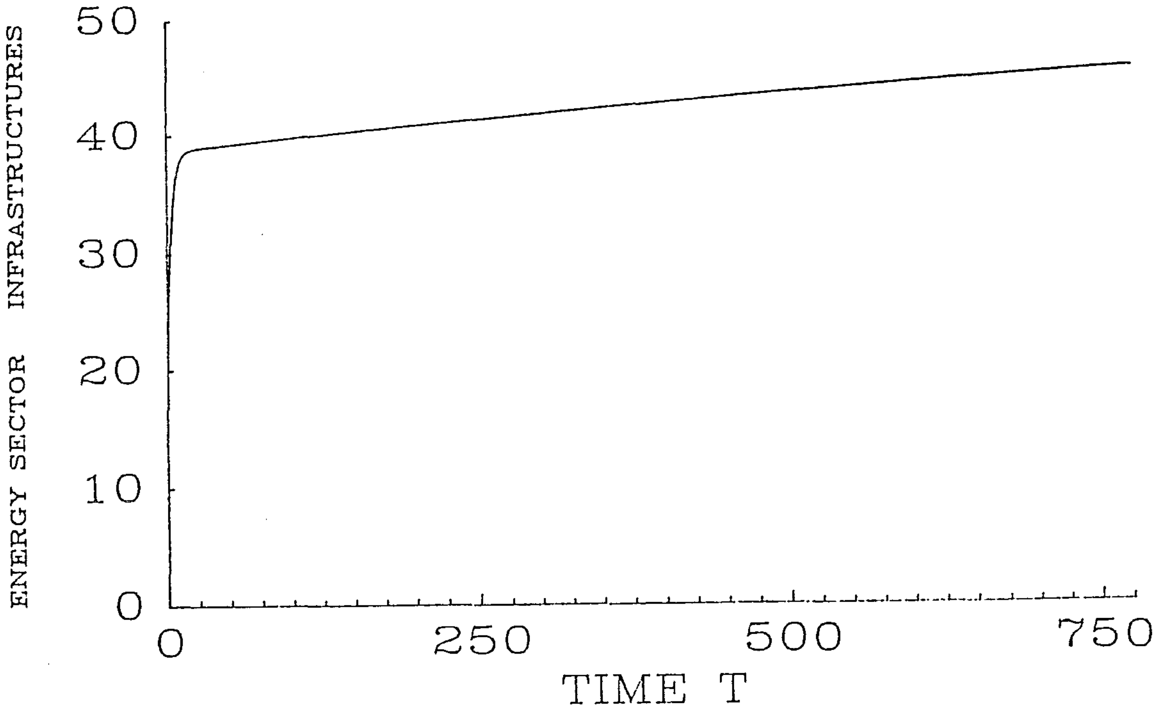


FIGURE 5 - NEW INFRASTRUCTURE ADDED TO THE ENERGY REFINING INDUSTRY

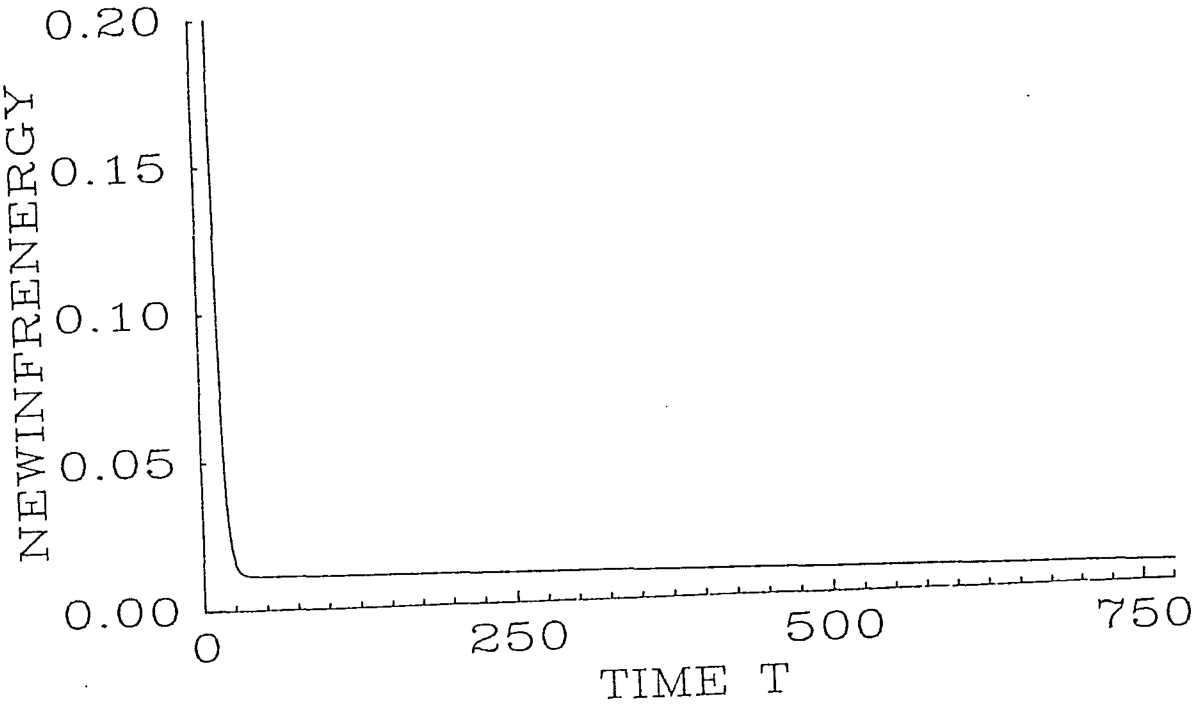


FIGURE 6 - YIELDS FROM THE ENERGY REFINING INDUSTRIES

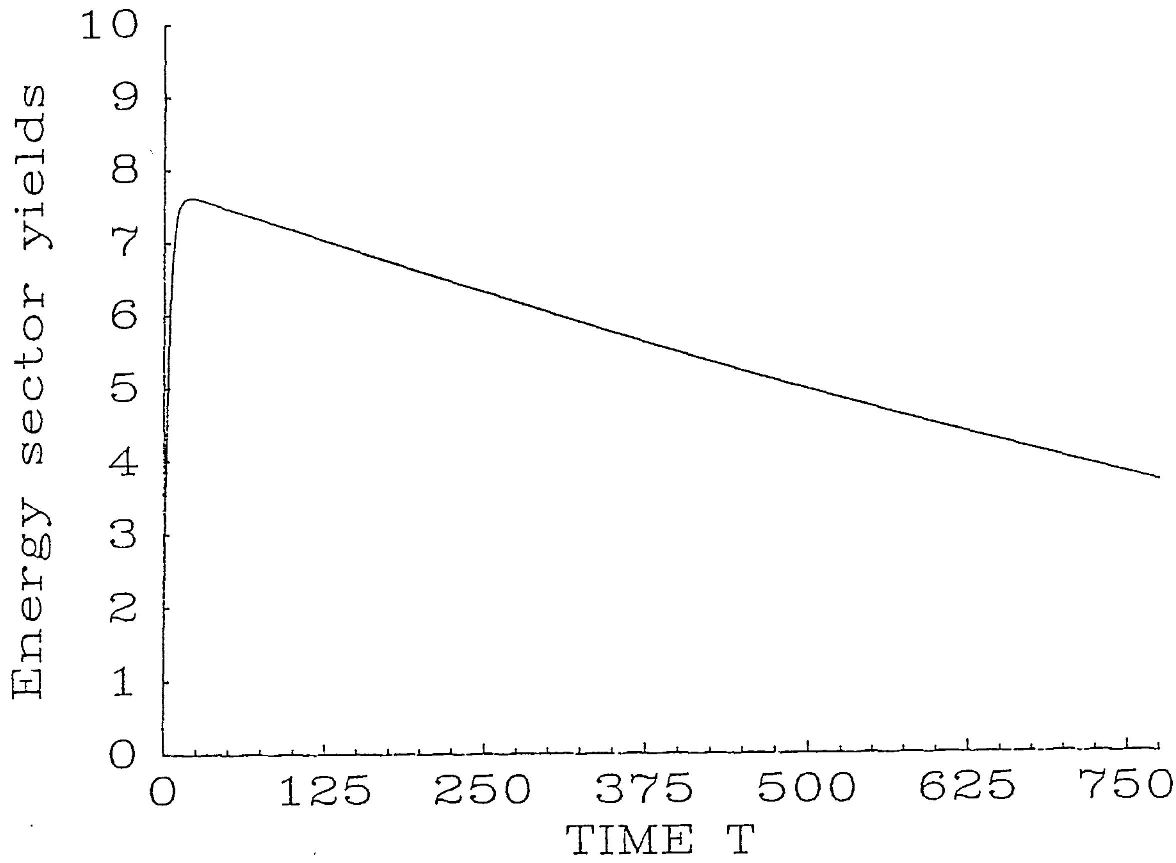


FIGURE 7 - ENERGY FROM THE SOCIO-ECONOMIC SECTOR FED BACK TO THE ENERGY REFINING INDUSTRIES

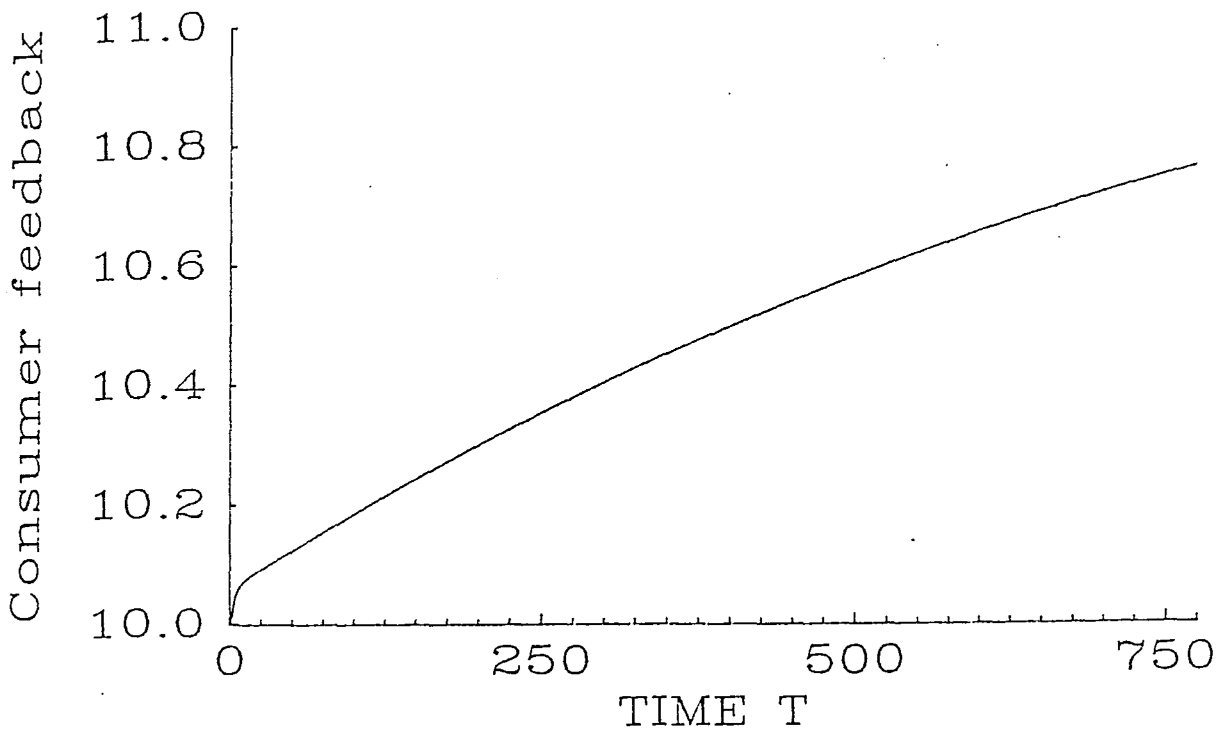


FIGURE 8 - ENVIRONMENTAL STOCK RESOURCES FOR THE ENERGY SUPPLY SECTORS

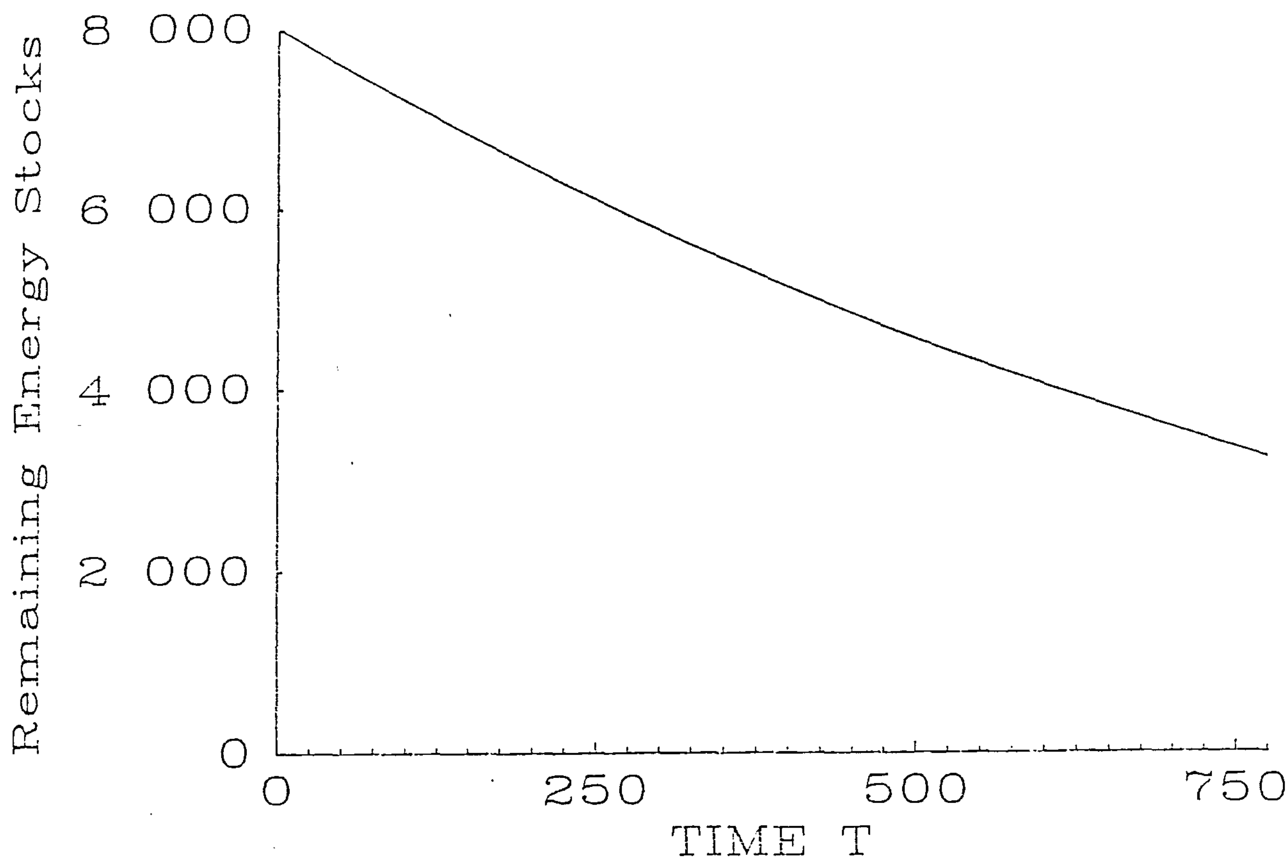


FIGURE 9 - INFRASTRUCTURE OF THE SOCIO-ECONOMIC SECTOR

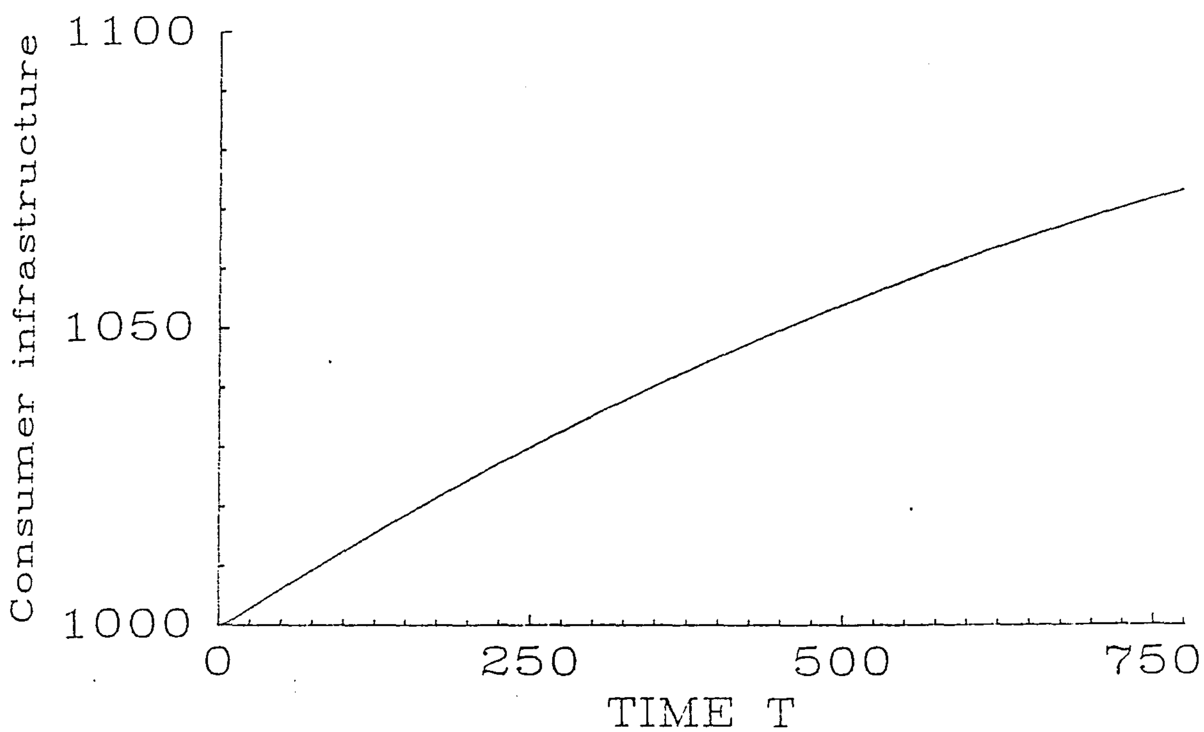


FIGURE 10 - NEW INFRASTRUCTURE ADDED TO THE SOCIO-ECONOMIC SECTOR

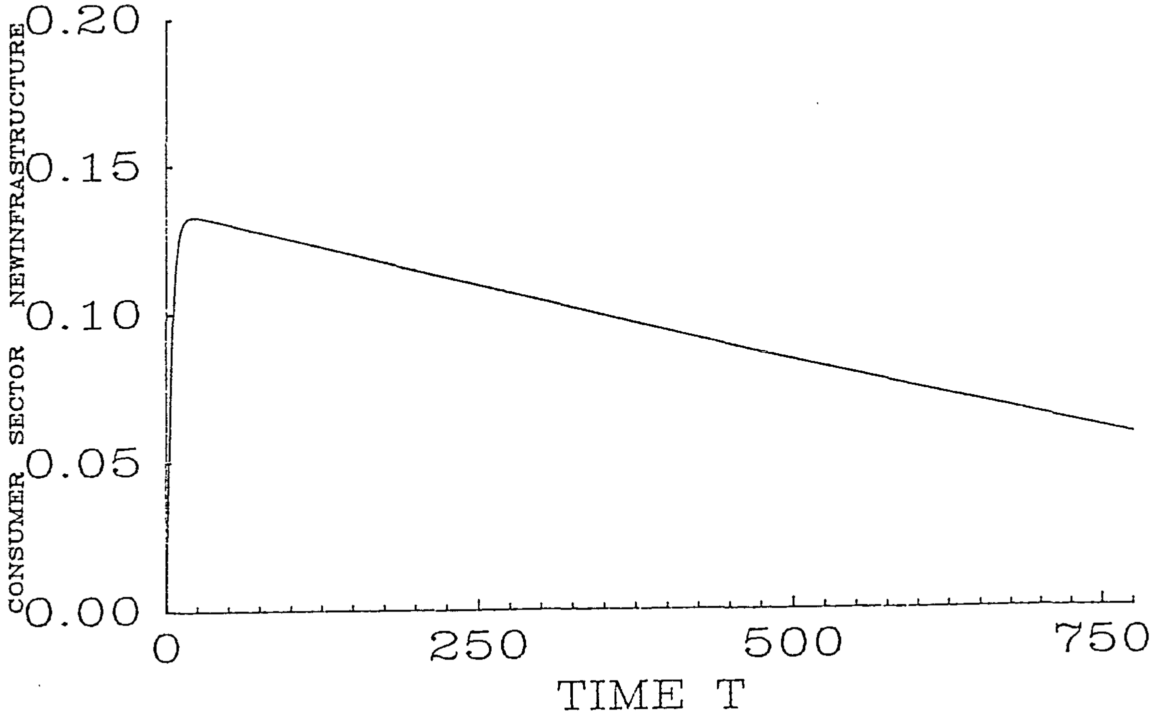
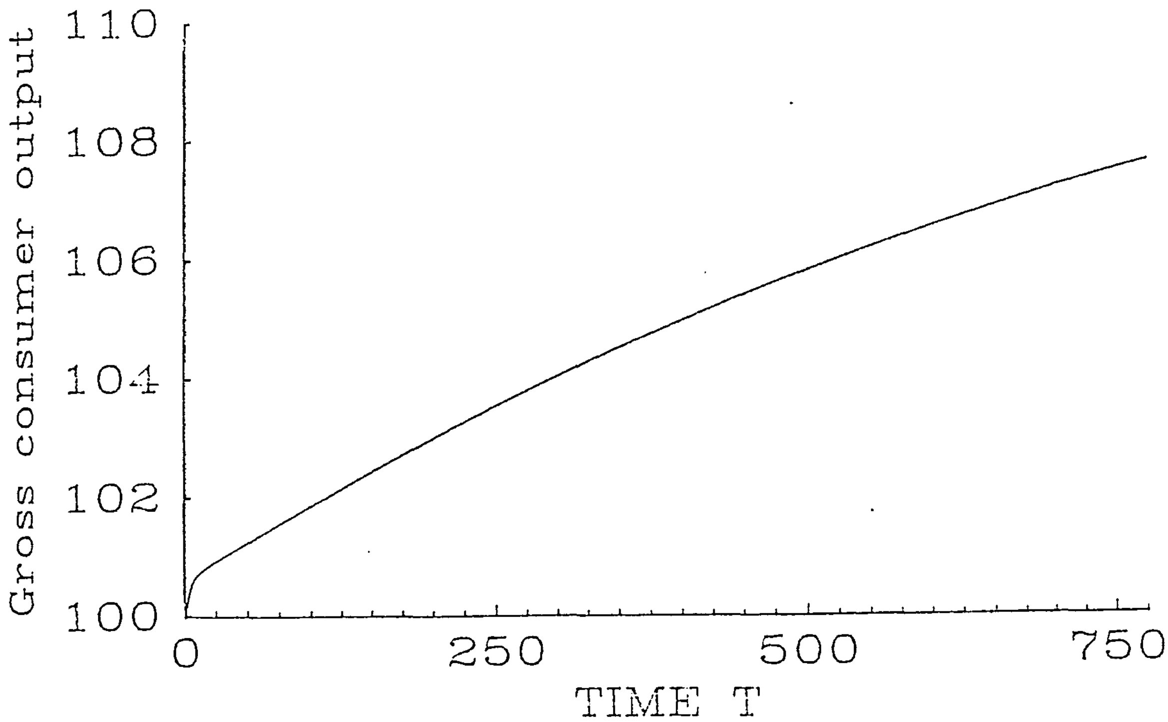


FIGURE 11 - GROSS ENERGY OUTPUT FROM THE SOCIO-ECONOMIC SECTOR WORKGATE



a damping mechanism, preventing the model from being swamped by a rapid growth in energy output from the energy refining industry. The value of the storage barely changes, because the energy yield is very small compared to the tank capacity. Hence it is a virtual constant, and the consumer flows will depend more on the infrastructure than anything else. The infrastructure increases over time, but the new infrastructure, after an initial 'kick', decreases. So while the infrastructure is getting larger, the rate of its growth is slowing down. This is reflected in the other consumer flows. The gross output, Figure 11 (similarly the operational consumerfeedback), depreciation (as for Figure 9) and consumerfeedback, Figure 7, all increase non-linearly, consistent with the growth pattern of the infrastructure.

5.2 Double Sector.

A single energy supply sector, which provides all of the energy required by the socio - economic sector, must obviously retain 100% of the energy supply market. When two stock sectors of the same parameters provide the energy required by the socio - economic sector (ie. an Availability of 8000 units and Accessibility of 5 for both stock sectors) their market shares as shown in Figure 12 are split exactly 50/50 for each sector. This happens because the Inceptdates for the stock sectors are exactly the same, therefore they penetrate the market at exactly the same time, and their Availabilities and Accessibilities are equal. So whatever happens to one sector must happen to the other sector. It would appear that two stock sectors with equal parameters coexist in a mutually beneficial manner. Neither sector dominates the energy market, rather, both sectors share the market in a peaceful and cooperative spirit. Other factors such as the remaining stocks, infrastructure development and energy flows show trends similar to the single stock sector case over time.

Certain differences do occur, however, between the single sector case, and the double sector case. An important difference is the total energy yield over time. It can be seen from Figures 6 and 13 that the sum of the energy outputs from the two sectors is increasingly larger than the energy output from the single sector over time. Initially, the energy yields from the single sector and two sector cases are the same, but with the passing of time, a greater discrepancy occurs between them.

A similar effect occurs with the graphs of the remaining stock resources,

FIGURE 12 - MARKET SHARES

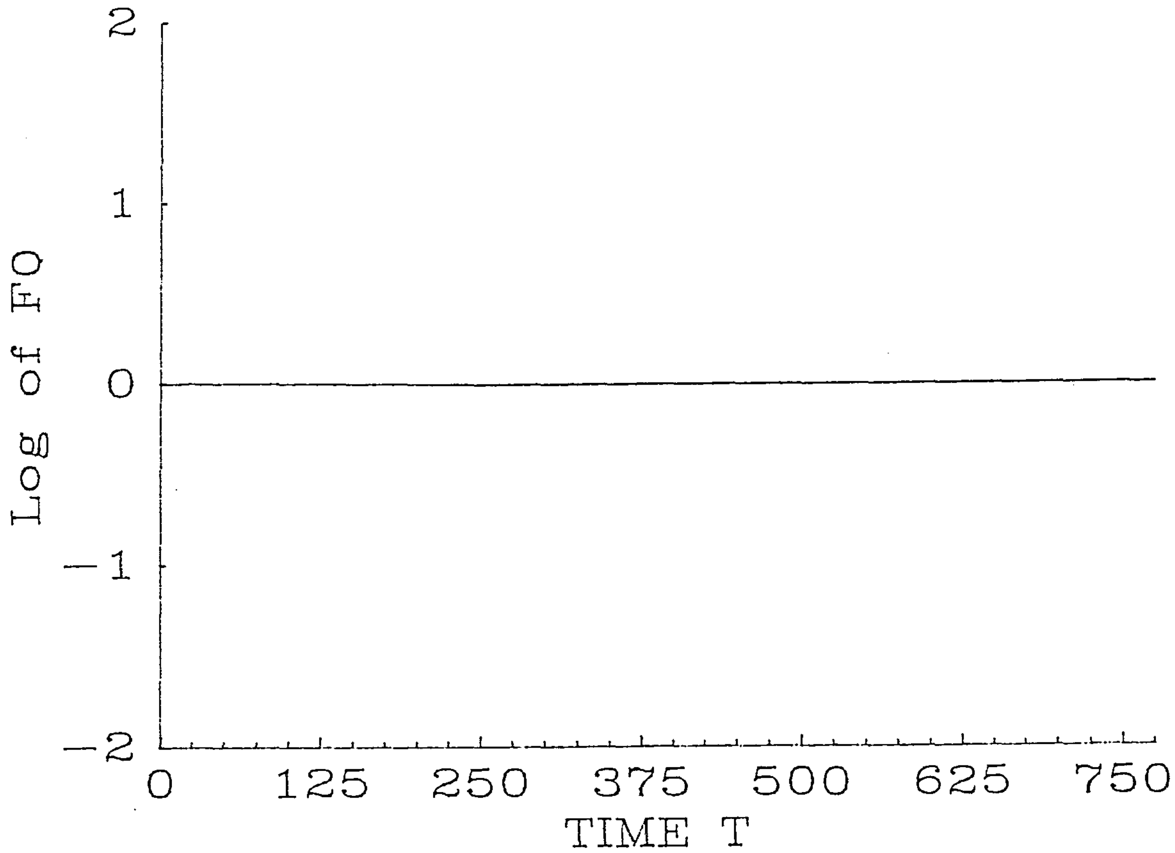
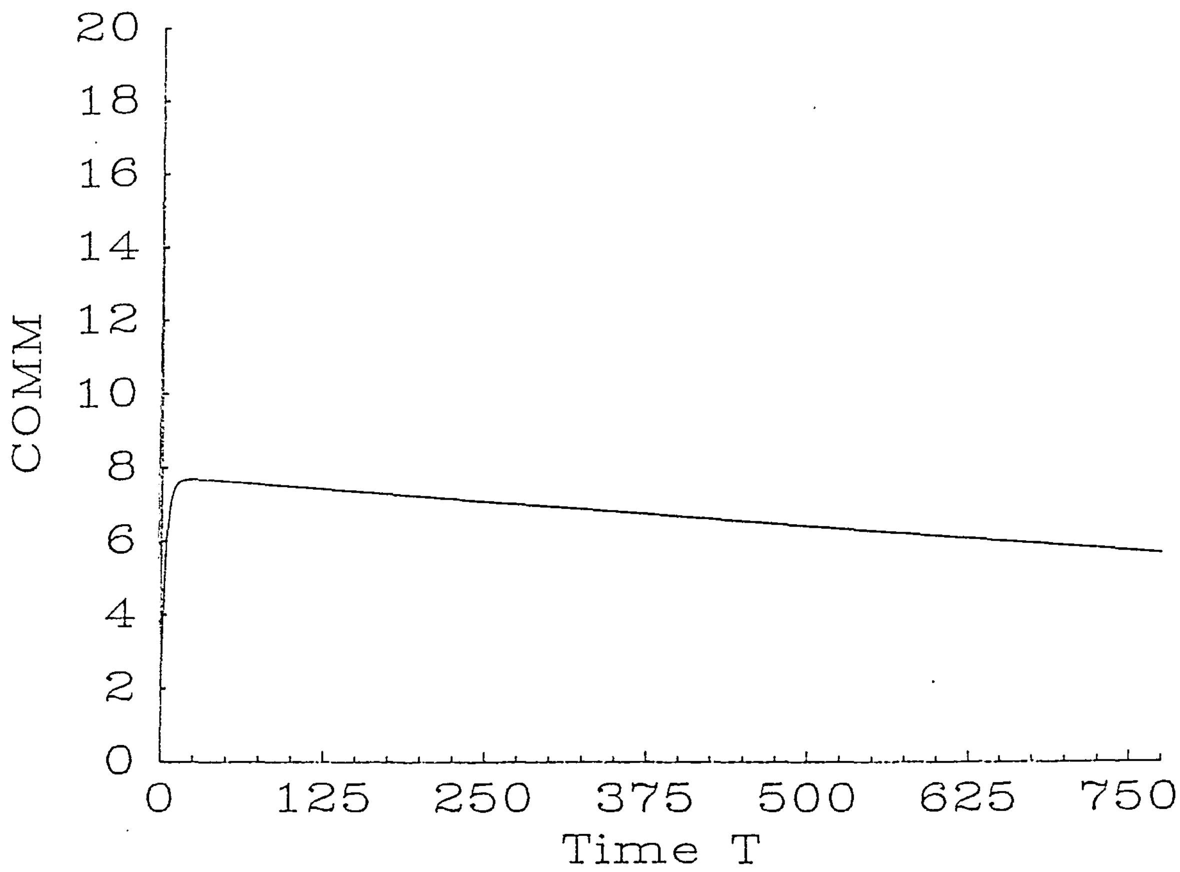


FIGURE 13 - YIELDS FROM THE ENERGY REFINING INDUSTRIES



(Figures 8 and 14), where a decrease from the original Availability value to the amount at the end of the run is not the same between the single sector and double sector cases. The double sector decrease is more than half the single sector decrease, so in total, it is greater (since there are two stocks) than the decrease in the remaining stock of the single sector due to the greater energy yield in the two sector case.

If the availability of the single sector is increased to 16000, being the sum of the availabilities of the two sectors, then the single energy supply sector yield is the same as for the two sectors, each with an availability of 8000. The infrastructure and energy flows of the socio-economic sector are the same as before. This sector is unaware of the number of supply sectors, the total availability being the only important parameter.

5.3 Displacing the Inceptdates by a one year differential.

The previous results and discussion apply to the Inceptdates of energy sectors being equal. But what happens when the Inceptdates are not equal, i.e. if they are displaced by a differential amount of at least one time step, ie. one year ? The Availability and Accessibility remain at 8000 units, and 5, for both sectors.

The results are striking. No longer is there harmonious coexistence between two energy sectors. Now there is an intense competitiveness by each sector to take control and dominate the energy market at the demise of the other sector.

Whichever sector has the earlier Inceptdate maintains the lion's share of the market from the start of the run, as shown in Figure 15, until a time is reached when it steadily loses market share, while the second sector gains what the first loses. There is a crossover point of 50% market share for each sector, after which the sectors continue their respective gains and losses. Finally, the second sector comes to dominate the market, as the first slips down to 1% levels and below. It is as if the rise in dominance itself seals the sector's own fate in a subsequent fall. After a time, the fortunes of each sector change, and the first sector steadily rises toward dominance, while the second sector drops from its high plateau.

In line with the market shares, the energy sector yields of Figure 16

FIGURE 14 - ENVIRONMENTAL STOCK RESOURCES FOR THE ENERGY SUPPLY SECTORS

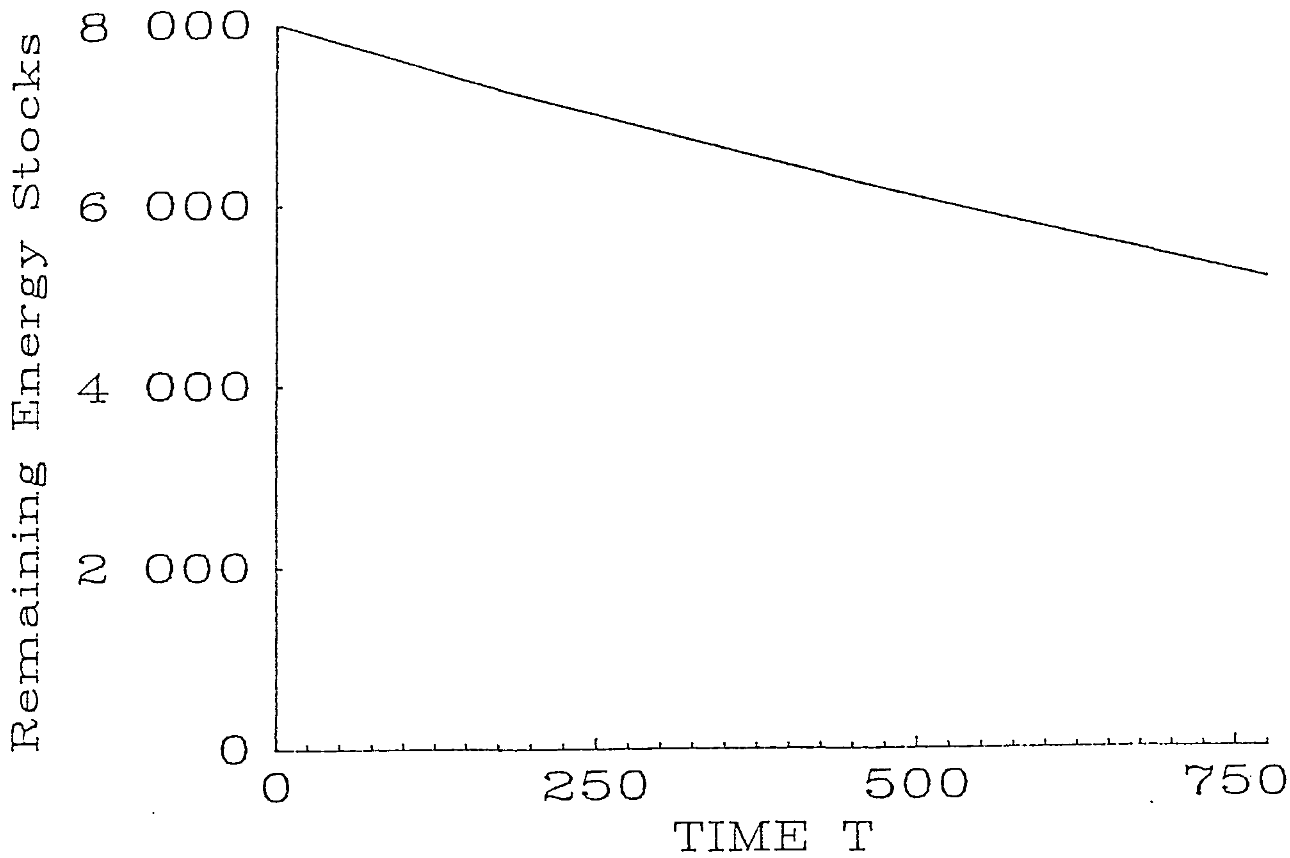


FIGURE 15 - MARKET SHARES

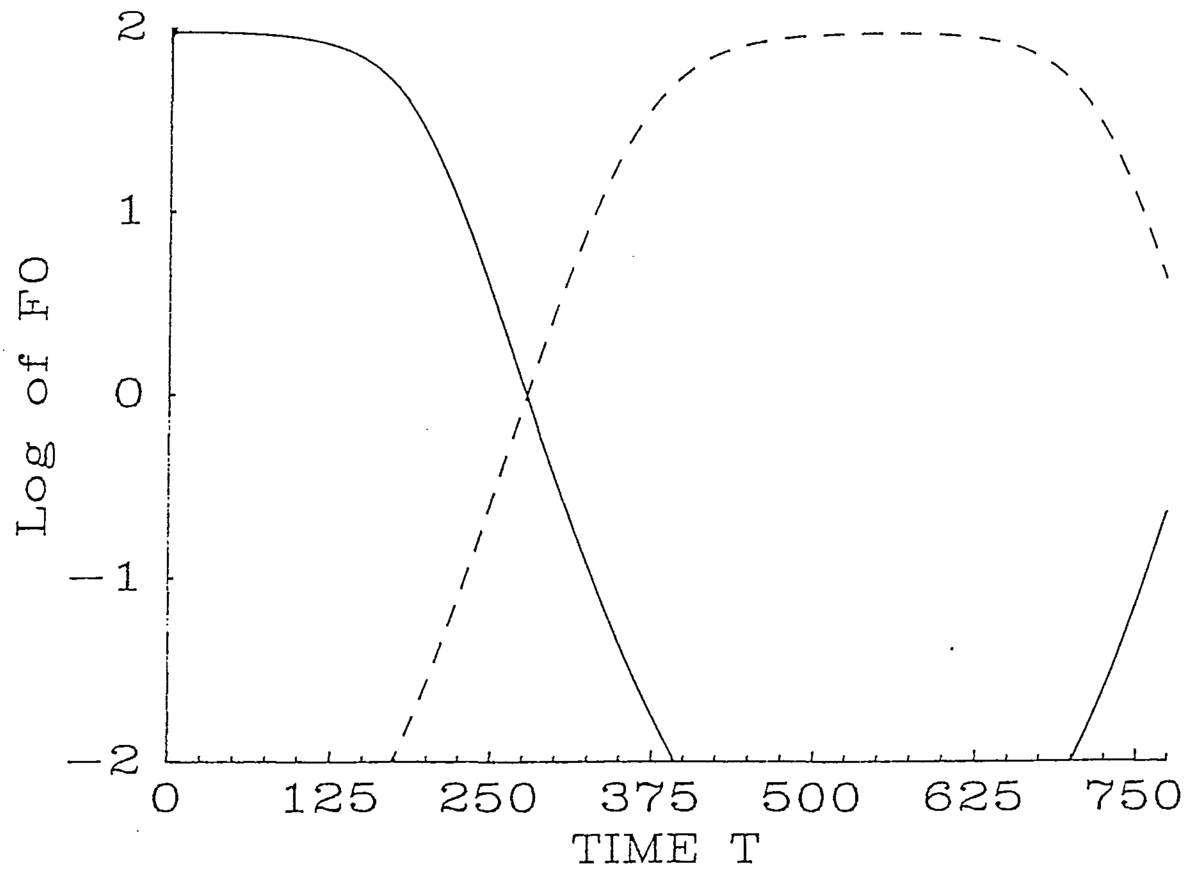


FIGURE 16 - YIELDS FROM THE ENERGY REFINING INDUSTRIES

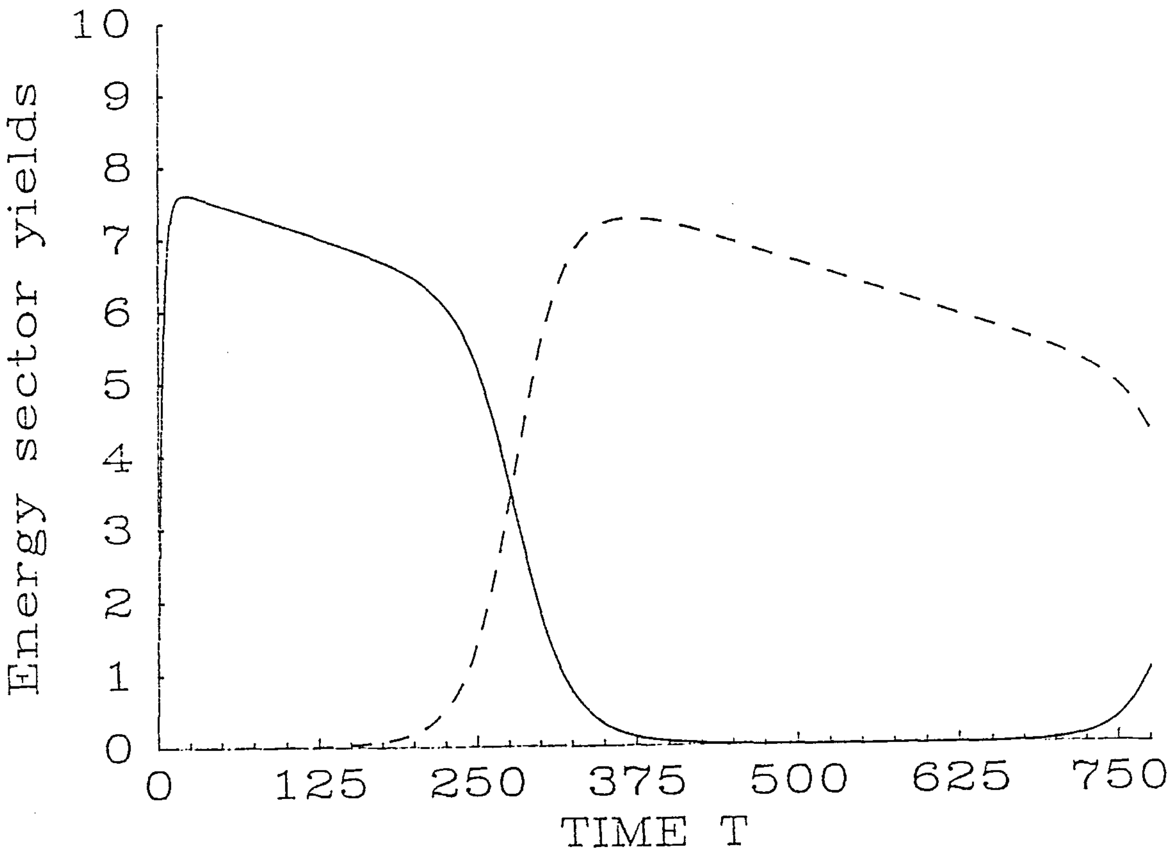
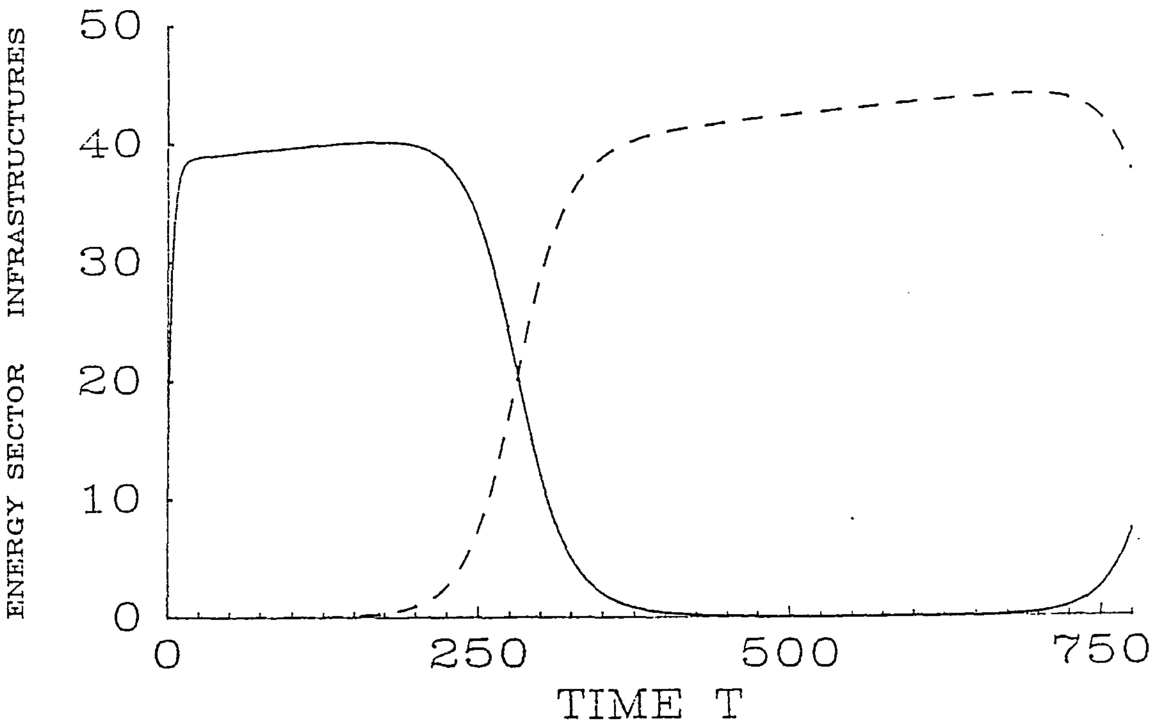


FIGURE 17 - ENERGY REFINING INDUSTRY INFRASTRUCTURES



follow the same pattern of rise and fall, although the shape of the curves is different due to the output of the dominant sector decreasing. On the other hand, the energy sector infrastructure of the dominant sector, Figure 17, increases. This is due to the addition of new infrastructure in each sector, as shown in Figure 18. The solid line of the first sector is initially very high, to build up in a short space of time the infrastructure capable of producing the initial energy output. It then rapidly declines to almost zero, thereby very slowly increasing the infrastructure of the first sector during its reign of dominance. Meanwhile, the second sector, represented by the dotted line, has no new infrastructure until the first sector new infrastructure begins to decrease to below zero, i.e. the latter takes a negative value, creating a shrinking infrastructure. At this point, the second sector new infrastructure oppositely parallels the first, by gaining what the first loses. The overall effect is a rapid decline in the infrastructure of the first sector to zero, and a corresponding rapid rise in the infrastructure of the second sector. From here until the next half cycle, the roles of sector domination are reversed, and it is the second sector which has dominion over the market. It gradually increases its infrastructure from the very small but positive increments of its new infrastructure. The operational energy feedbacks are scaled versions of the energy sector yields.

The remaining energy stocks of Figure 19 are also different. The stock of the first sector is consumed initially, because of its dominance, while the second stock sector appears to endure very little, if any consumption. The turning point occurs when the sectors swap domination roles - now the first sector stock level remains almost constant, but the second stock sector is being depleted.

The socio-economic sector infrastructure of Figure 20 follows an almost linear path, increasing with time. However, examination of the new infrastructure of the socio-economic sector reveals a sudden initial rise, followed by a steady decrease, then a small rise and a slow decrease. This small rise is concurrent with the rise in dominance of the second energy sector, indicating a mini 'boom' in the economy, (Figure 21). The gross output of the socio-economic sector is very similar to the growth of the infrastructure.

Thus there is a pattern of oscillation between sector dominance and submission. Whenever one sector is dominant, the other sector is in submission, and the decline of one is the rise of the other. (The market shares of both sectors together always add to make 100%.) This cyclic fluctuation is in sharp contrast to the equal sharing of energy requirements when the Inceptdates are the same.

The patterns over time of these energy destinies have been presented in detail for the cases of a single energy supply source of specified Availability

FIGURE 18 - NEW INFRASTRUCTURE ADDED TO THE ENERGY REFINING INDUSTRY

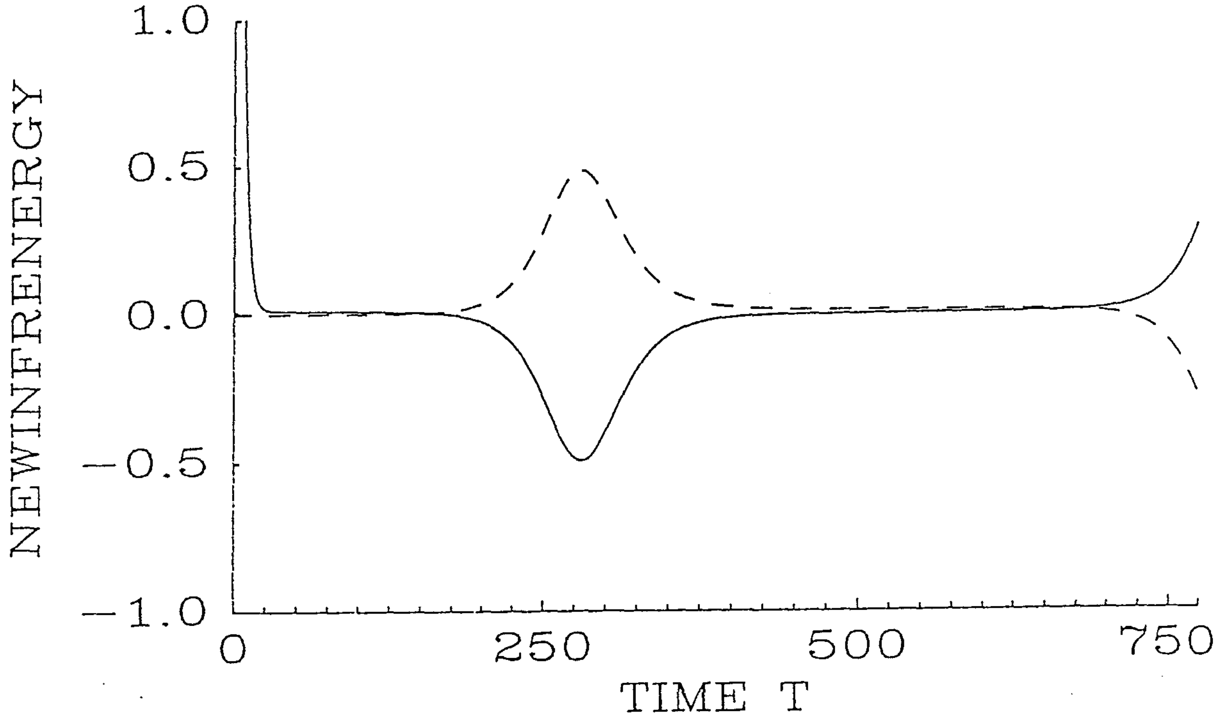


FIGURE 19 - ENVIRONMENTAL STOCK RESOURCES FOR THE ENERGY SUPPLY SECTOR

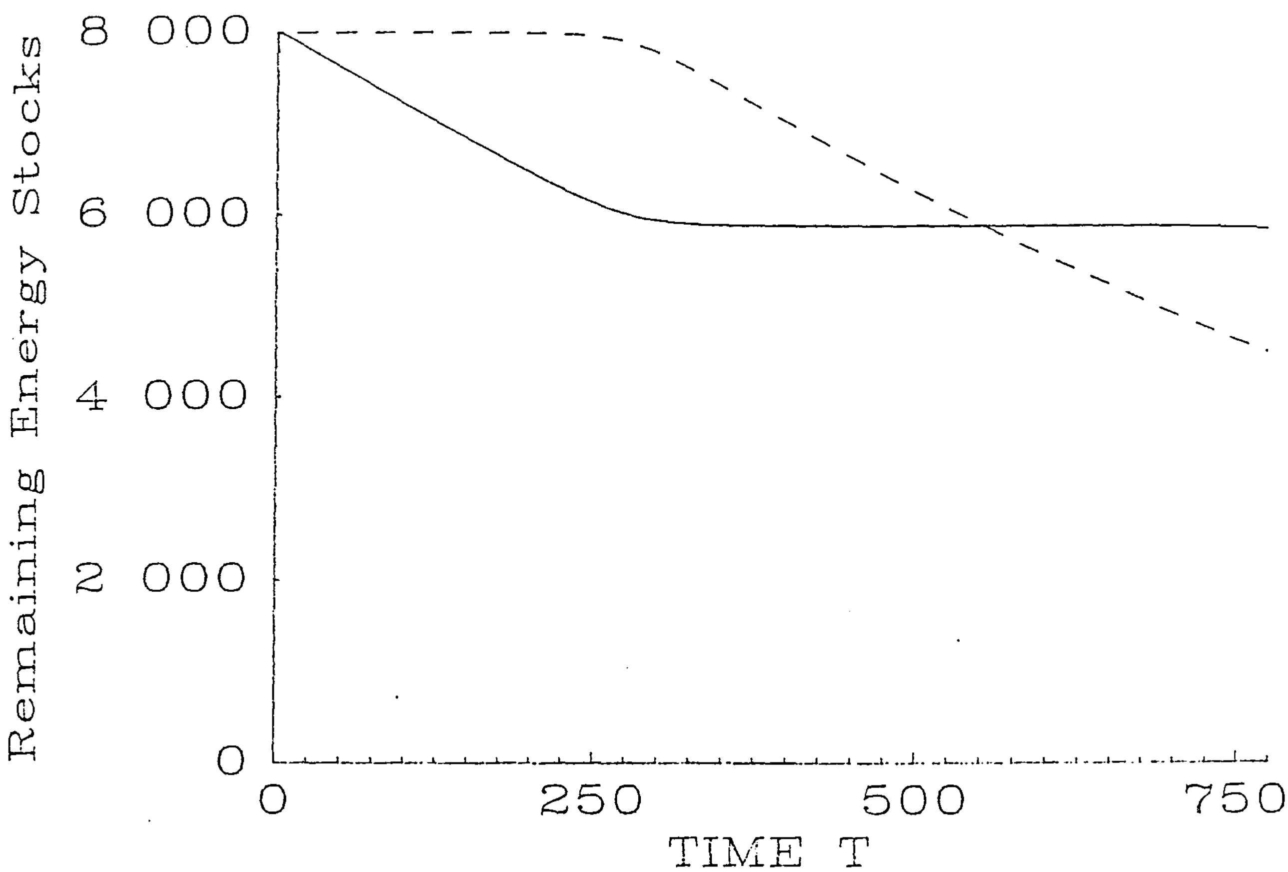


FIGURE 20 - INFRASTRUCTURE OF THE SOCIO-ECONOMIC SECTOR

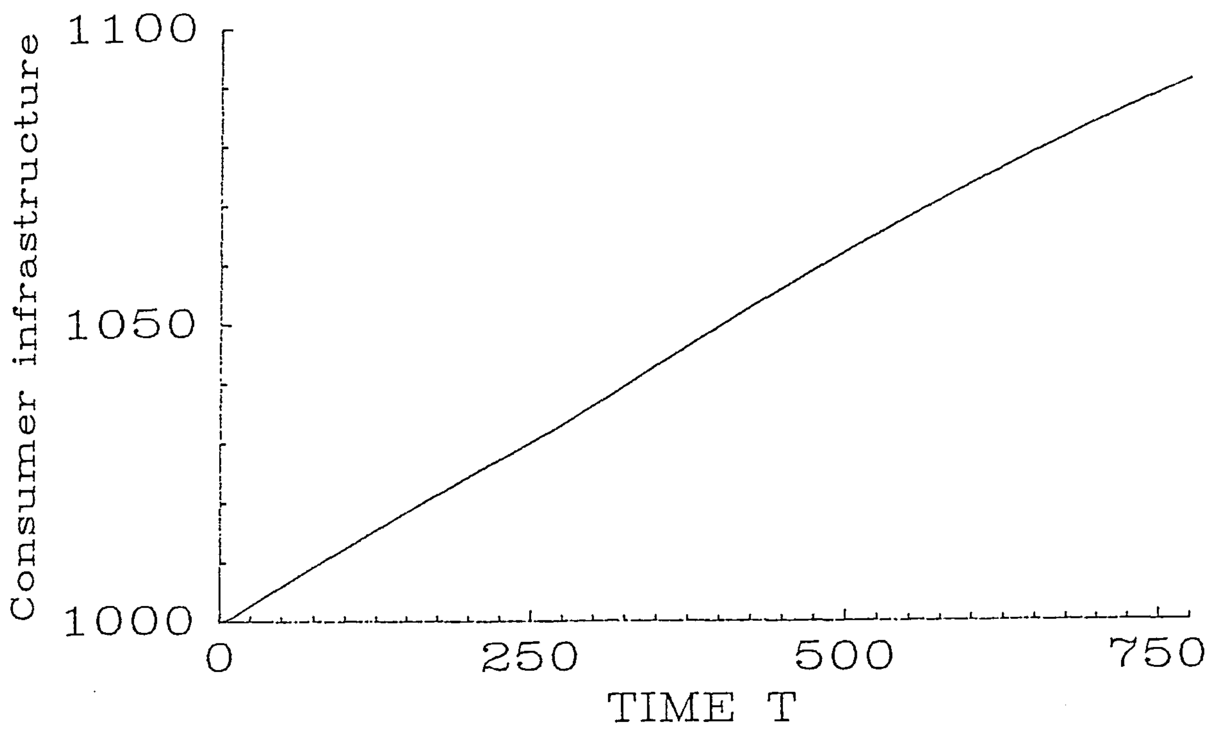
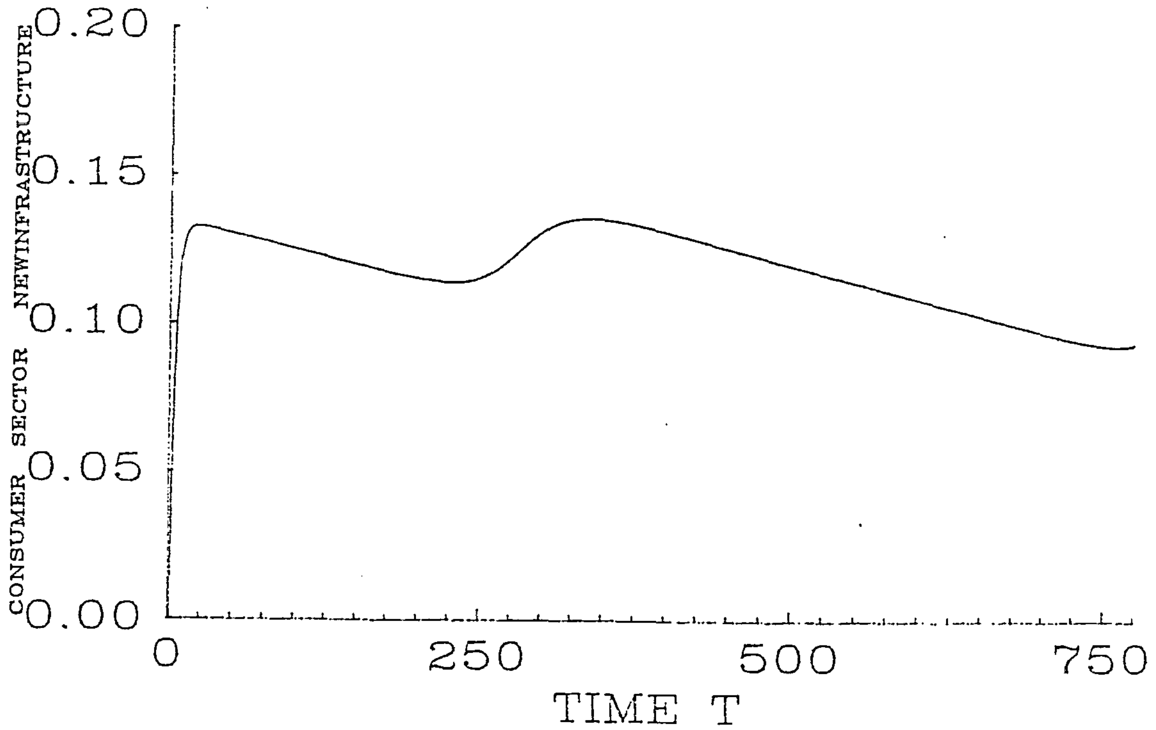


FIGURE 21 - NEW INFRASTRUCTURE ADDED TO THE SOCIO-ECONOMIC SECTOR



and Accessibility. In addition, when two such sectors, each with with identical parameters come into the market at the same time, they each share in the supply of energy to the socio-economic sector. They behave in a cooperative manner and mutually benefit from such a development. However, if they penetrate the market at different times, they behave aggressively, each vying for market domination over the other. When this happens, there is a cyclic pattern of rise and fall of each sector, one sector in antiphase with the other.

Chapter 7 investigates the system behaviour if the energy sector parameters are changed relative to one another with an inception time differential.

Chapter 6

General results for 2 stock sectors with an inception time differential.

The model representation of Chapter 6 differs from Figure 3 in two aspects: the first is that the flow source sector has been removed, and the second is that the 3 stock sectors have been reduced to 2. These alterations leave only 2 stock sectors and, of course, the socio-economic sector.

6.1 Changing Availabilities.

From the market share graph of Figure 22, with equal Availabilities (8000 units) and equal Accessibilities (25) but a 1 year inception time differential, a feature is the lengthy time delay of the second sector. It doesn't reach the 1% level until after 235 years beyond its Inceptdate. However, it rises, peaks and falls in antiphase with the first sector, dominating the market for a short time at the demise of the first sector, which then wrests back control to its former heights.

Altering only the first sector Availability to 4000 units, the first sector dies away earlier (Figure 23) but it doesn't recover during the length of the run (although it may do beyond the 1000 year range shown). Corresponding to the earlier demise of the first sector is the earlier rise of the second sector, which levels off at its peak height for the remainder of the run.

When the Availability of the second sector is reduced to 4000 (Figure 24) and that of the first sector resurrected to 8000, then the result is very similar to having equal Availabilities, except that the rise of the second sector is not as great, and the corresponding fall of the first sector is not as low.

These results suggest that a lesser Availability of the second sector (rela-

FIGURE 22 - MARKET SHARES

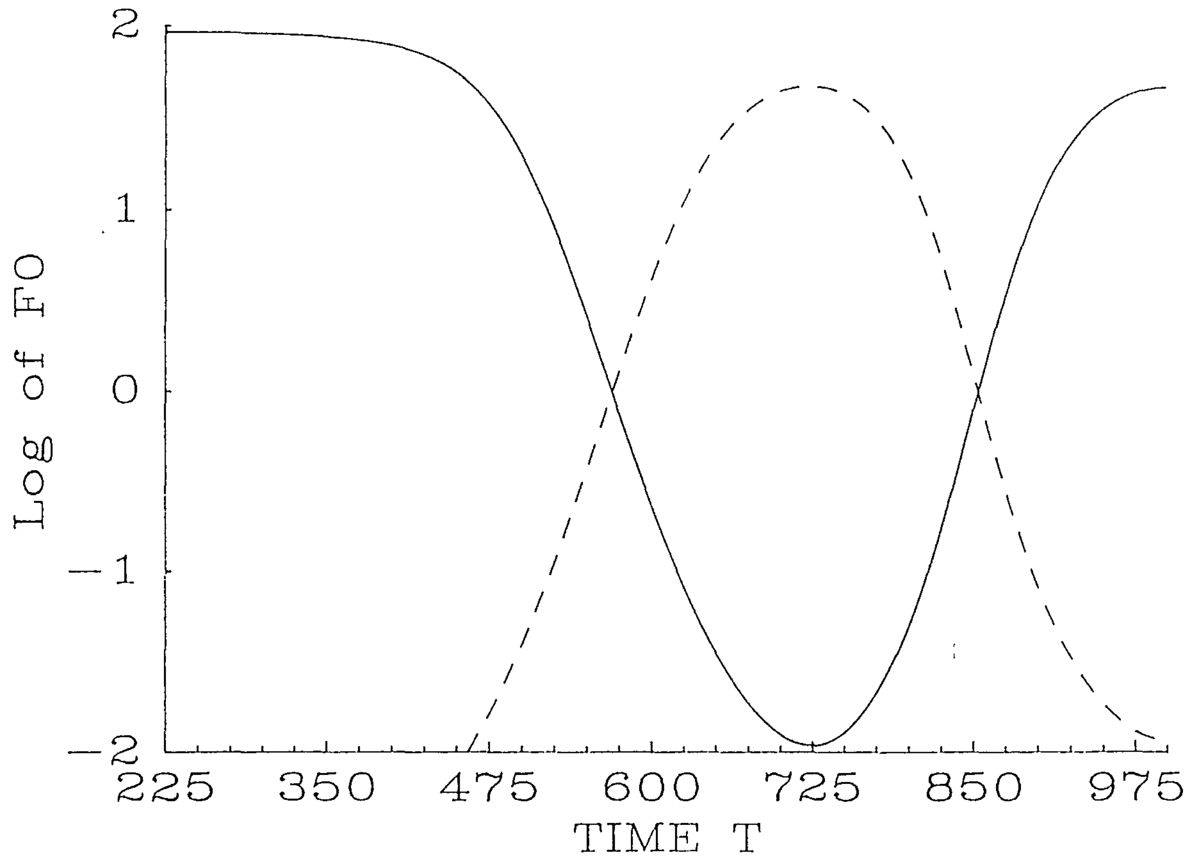


FIGURE 23 - MARKET SHARES

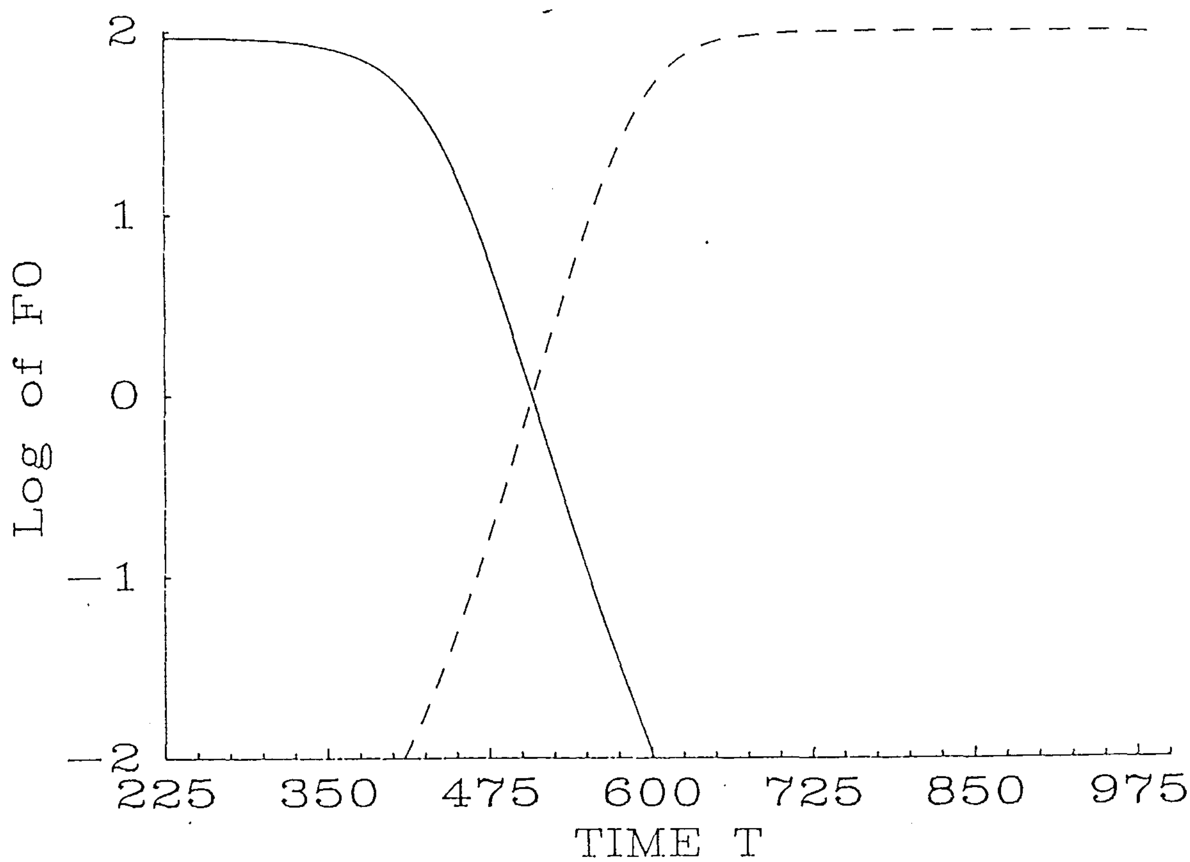


FIGURE 24 - MARKET SHARES

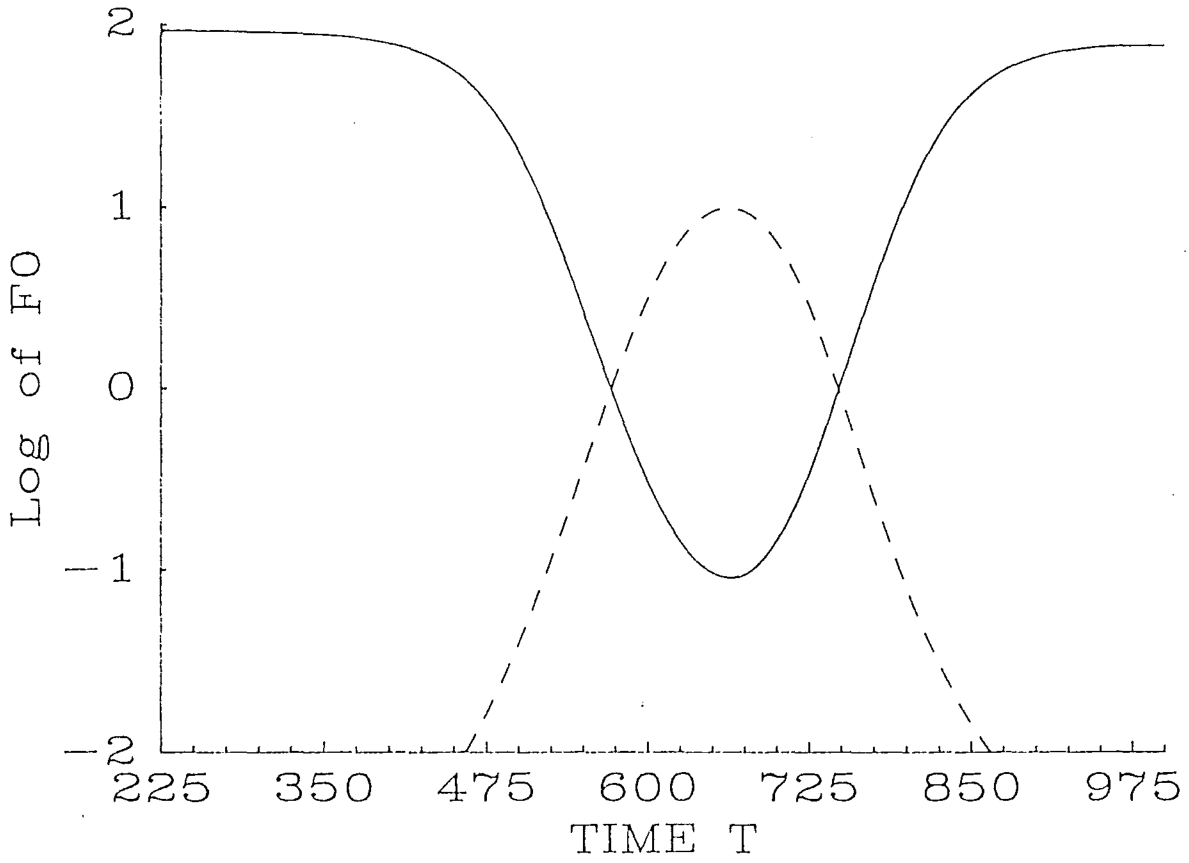
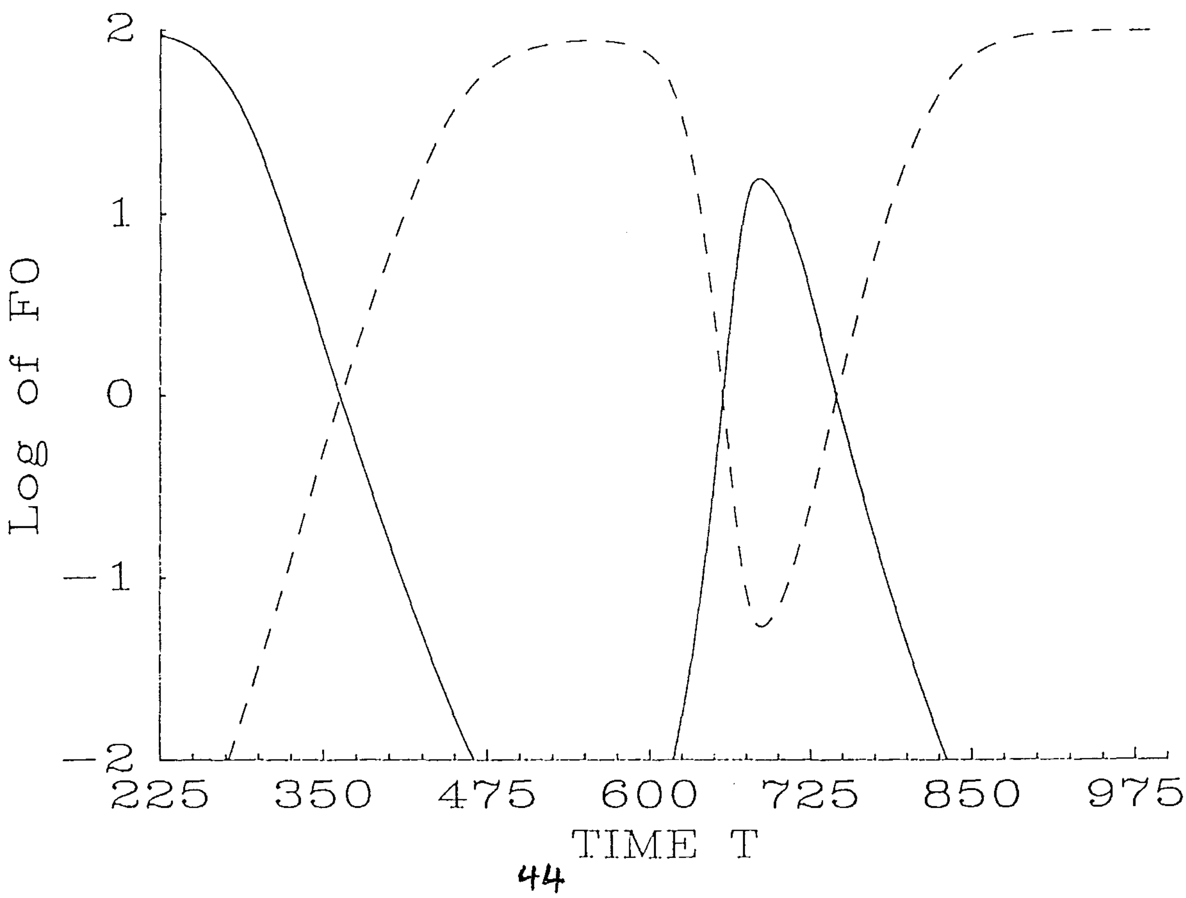


FIGURE 25 - MARKET SHARES



tive to the first) is not a significant factor in determining the changing market patterns, but a greater Availability is, given an inception time differential.

6.2 Changing Accessibilities.

When the Availabilities of the two sectors are held constant at 8000 units each, but the Accessibilities are changed, the following results are observed.

The Accessibility of the second sector is held at 25, but changed to 20, 15 and 10 for the first sector. Using Figure 22 with equal Availabilities and Accessibilities as a reference, pertinent comparisons are made below.

First sector Accessibility = 20, Figure 25.

The second sector (dotted line) reaches the 1% level much sooner than for Figure 22, its peak is higher, and it doesn't drop as far down. There is a resurgence of the second sector in Figure 25, and the rise and fall to below the 1% level of the first sector (solid line) both of which are not apparent in Figure 22.

First sector Accessibility = 15, Figure 26.

The effect of lowering the second sector Accessibility to 15 is pronounced, as demonstrated by Figure 26. The second sector reaches the 1% level much earlier (under 25 years), it rises with a steeper slope, it dominates for a far longer time, and falls abruptly. It then rises steeply again for a short time span.

First sector Accessibility = 10, Figure 27.

Figure 27 is very similar to Figure 26, but with slightly steeper slopes and sharper corners. In both Figures 26 and 27, the first sector tends to re-emerge around the 725 year mark. This date seems unchanging, and if the trend continues, the lower the Accessibility of the first sector, the more the date of re-emergence of the first sector will converge to 725 years (or thereabout).

FIGURE 26 - MARKET SHARES

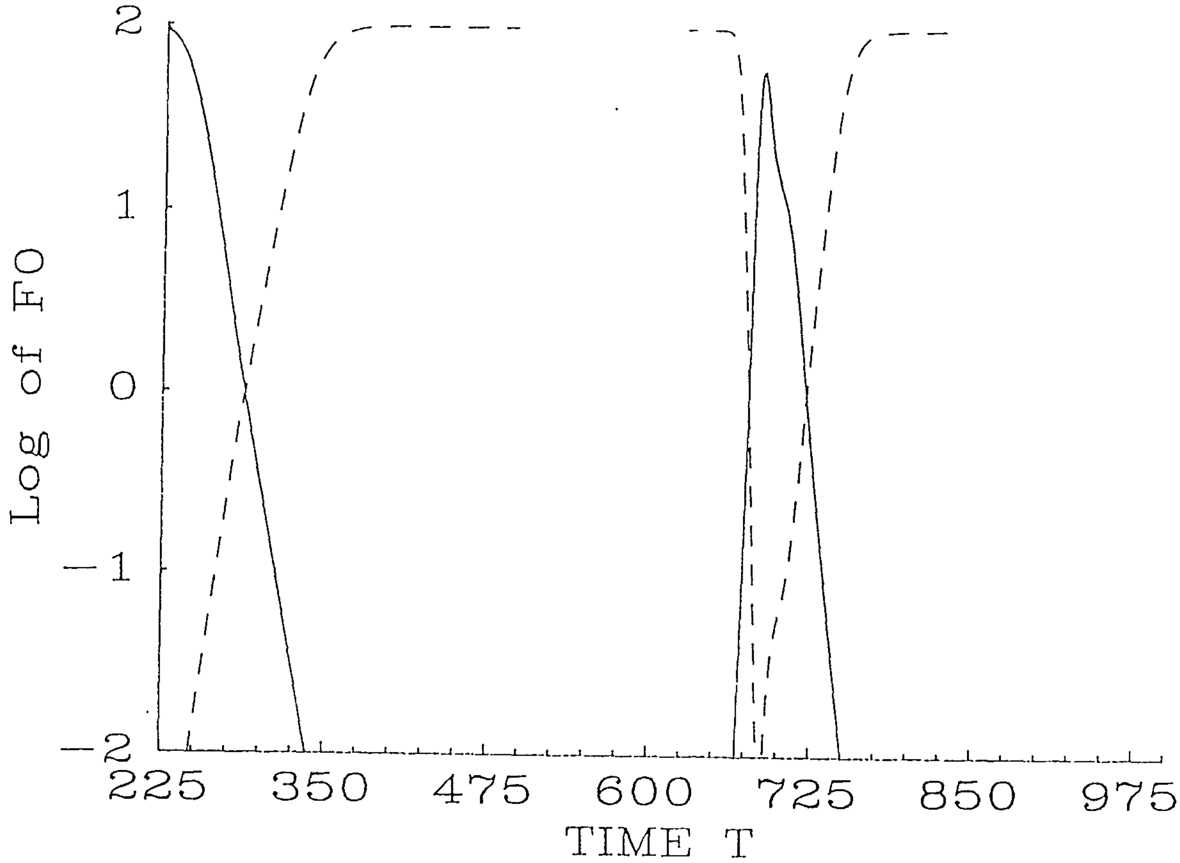
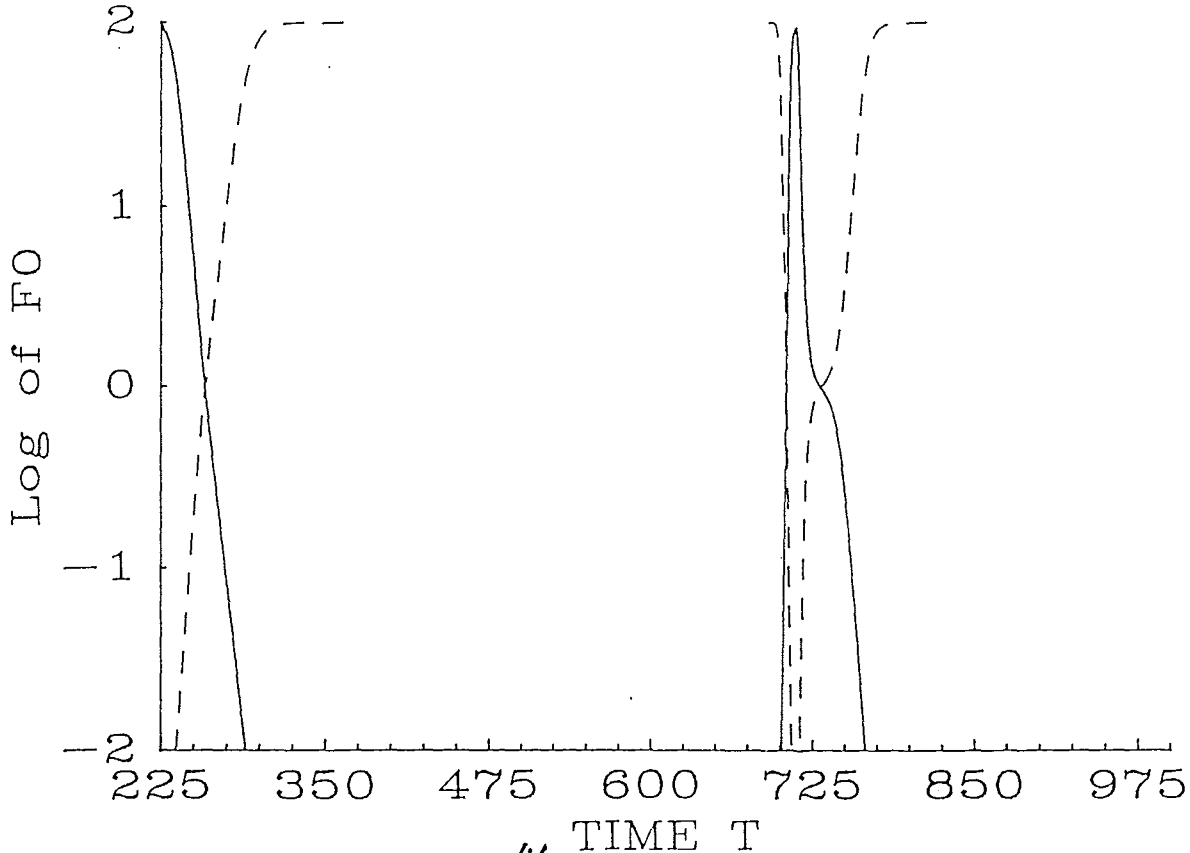


FIGURE 27 - MARKET SHARES



6.3 Changing Inceptdates.

Finally, maintaining both the Availabilities and Accessibilities constant for both sectors as per Figure 22, the Inceptdate of the second sector is varied (Figure 28). It is shifted forward in time by 300 years, but suprisingly, the 1% level shifts forward by only 100 years, and the second sector seems to rise, then flatten out to dominate the market share - it doesn't rise, peak and fall as in Figure 22. This means that by merely shifting the second Inceptdate (relative to the first), the pattern of Figure 22 is *not* replicated further downstream.

Furthermore, in changing both Accessibilities to 5 (Figure 29), thereby maintaining a one to one ratio, there is little difference between Figures 28 and 29 except in the gradient of the slopes. Therefore, the point of penetration at the 1% level is independent of the absolute levels of Accessibility.

If each sector Accessibility is held at 5, but the Inceptdate of the second sector shifted forward in time by a hundred years from the first sector, and then to only one year after the first sector, (Figures 30,31) the time difference at the 1% level is only 15 years for the second sector between the two runs. But the inception differential at the 0.1% level is 100 years. Hence it can be concluded that there is definitely not a one to one matching between the shifting of an Inceptdate, and the time at which the 1% level (or indeed anything above this) is reached.

6.4 Induced guidelines.

These simulation runs provide us with a few tentative guidelines on *how* the model reacts to external parameter changes, for two and only two stock sectors. These guidelines are summarised below. The comparisons are relative to a reference of equal Availabilities and Accessibilities.

1. When the Accessibility of the second sector is higher relative to the first sector, the normal time delay between the 1% levels of each sector is radically decreased.

2. When the Availability of the second sector is greater than that of the first sector, the market pattern is altered by the second sector enjoying a

FIGURE 28 - MARKET SHARES

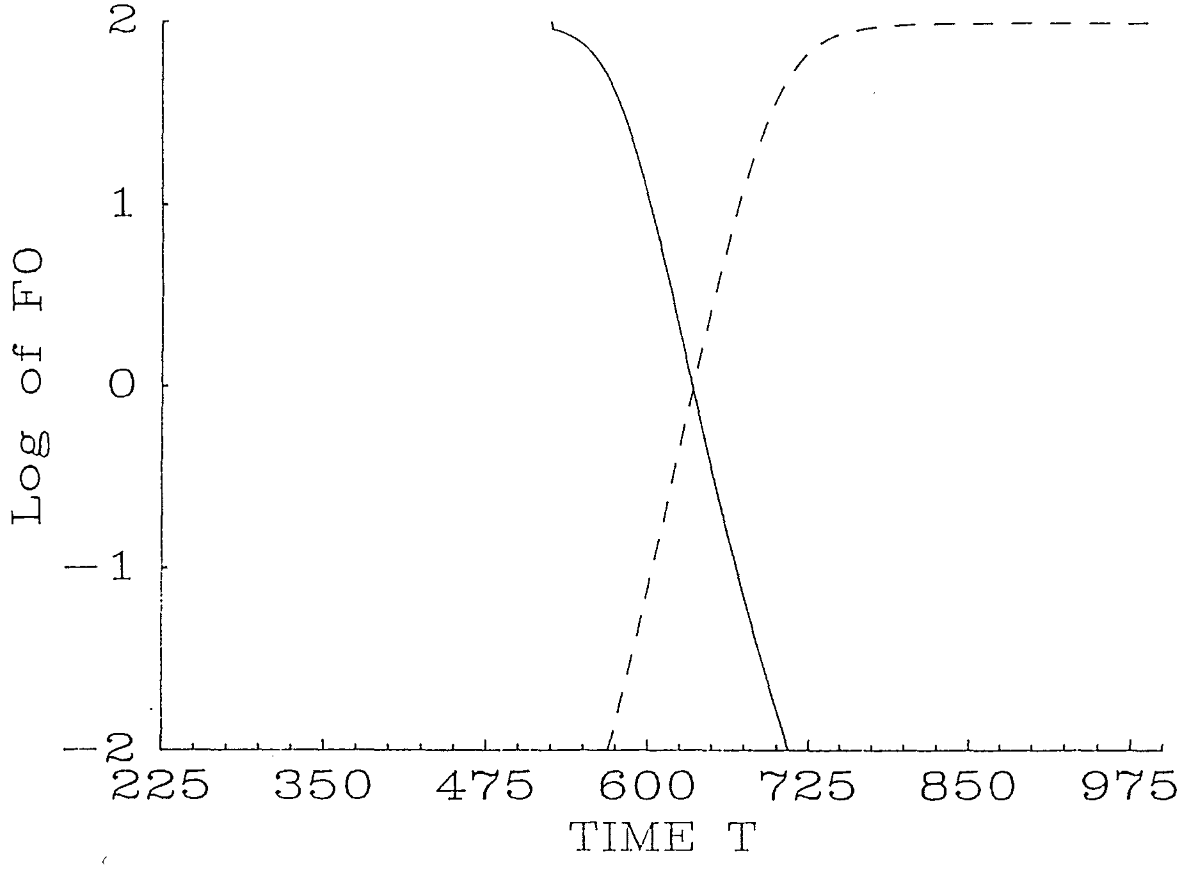


FIGURE 29 - MARKET SHARES

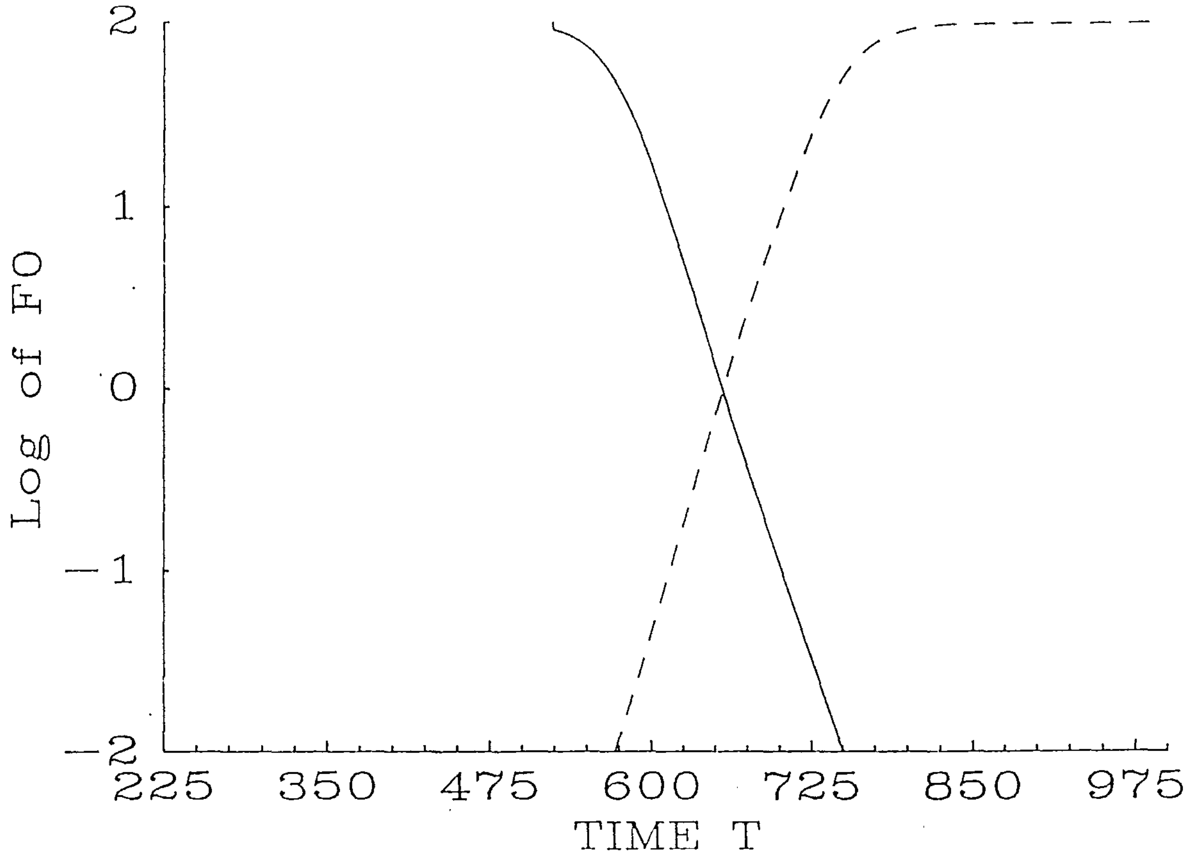


FIGURE 30 - MARKET SHARES

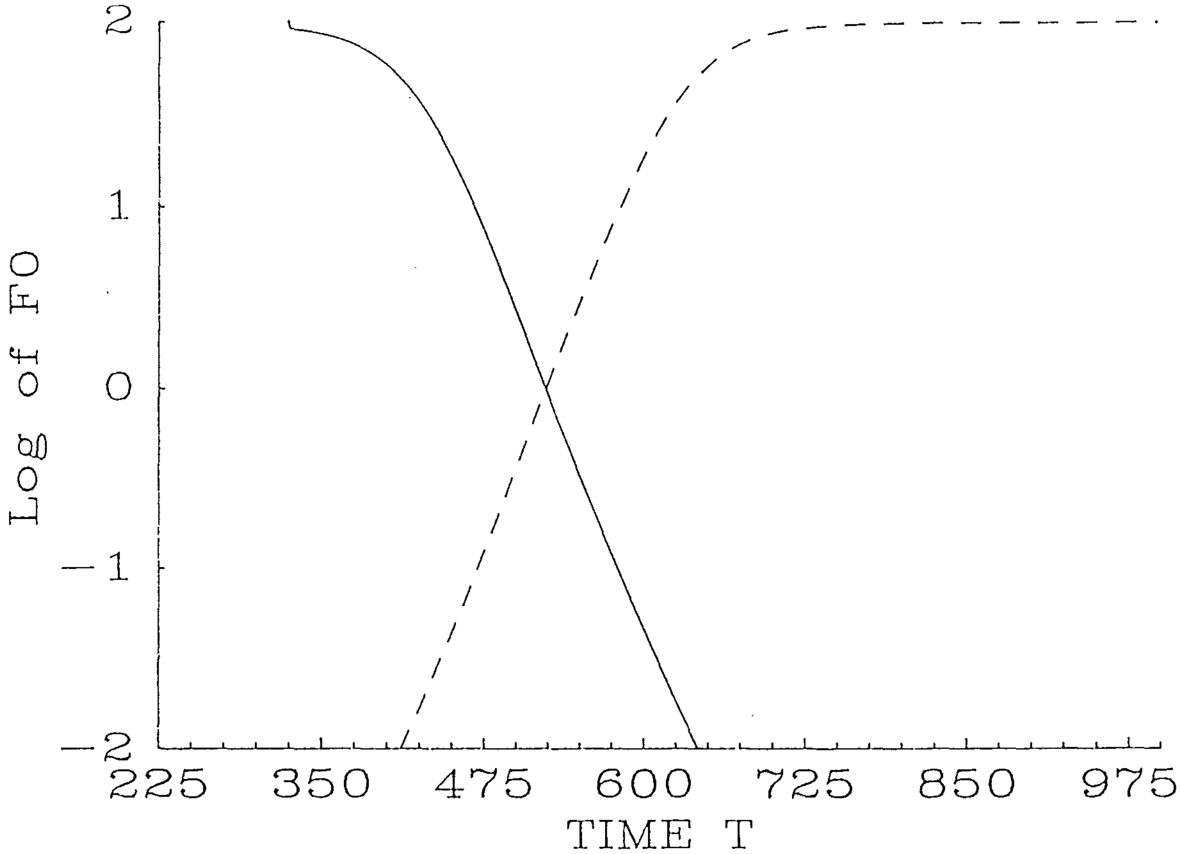
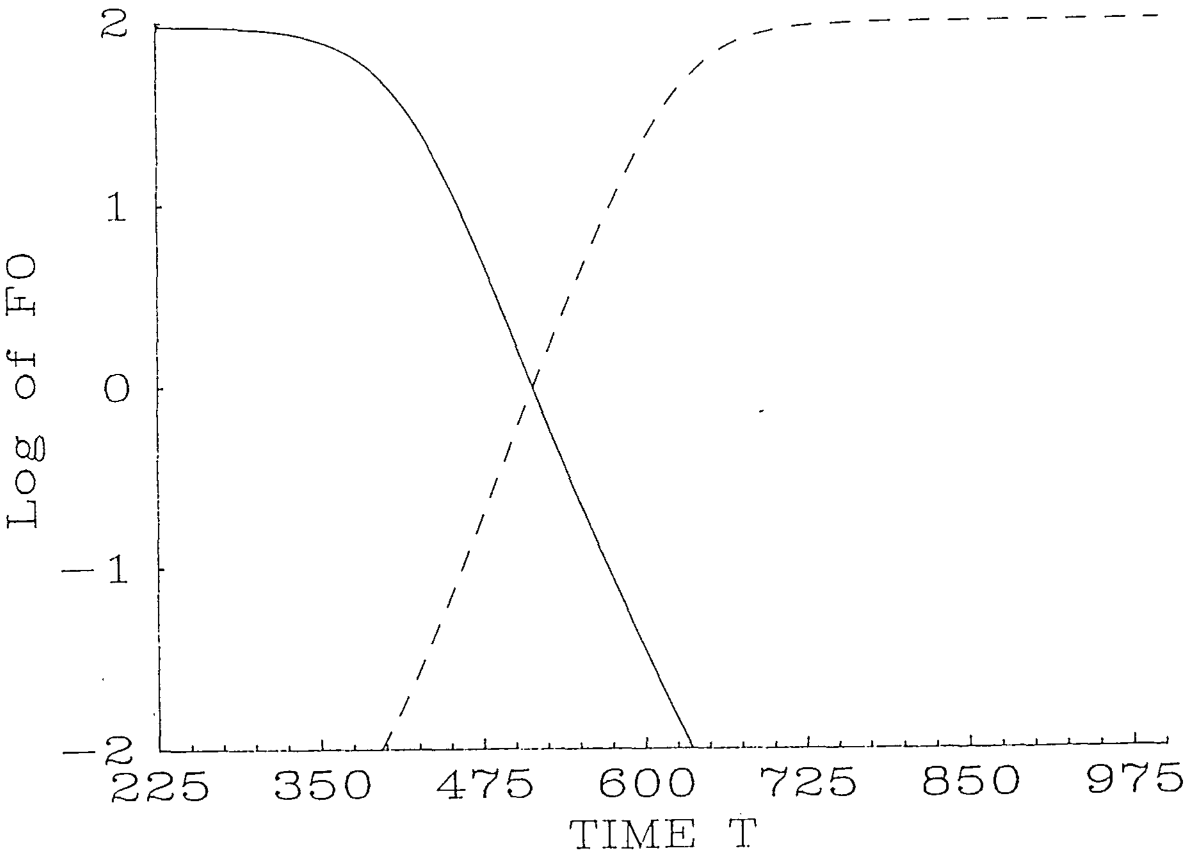


FIGURE 31 - MARKET SHARES



lengthy period of domination in market share. But when the Availability is less than that of the first sector, the pattern is not greatly affected.

3. Shifting the Inceptdates relative to each other does not correspond to a shifted pattern. This phenomenon is independent of the absolute values of Accessibility.

Chapter 7

A further investigation of 2 stock sectors with changing parameters and an inception time differential.

This chapter differs from Chapter 6 (General Results for 2 Stock Sectors) in that it examines the results of parameter changes more closely, and uses other graphed quantities in explaining the dynamics.

A two stock sector simulation is run on the energy substitution model for 3 separate cases. The first case sets the Availabilities and the Accessibilities of both stock sectors to be equal, while the second case sets both Availabilities equal but alters the Accessibility of the first sector to equal half the Accessibility of the second sector. The third case reverses the sectoral Accessibilities of Case 2.

The Inceptdates are similar in all 3 cases - they are assigned to be the start of the program run for the first sector, and one year later for the second sector, giving an inception time differential of one year. The simulation run begins at year 225 (a convenient point to start) and runs on to the year 1000, spanning a total of 775 simulated years. The start and finish points are arbitrary - what matters here is the actual timespan, in this instance, 775 years.

Case 1. Equal Availabilities and Accessibilities.

The Availability of both sectors is assigned 8000 units, while the Accessibility of both sectors is assigned 10.

The graph (Figure 32) of log F/(1-F) (or log F0) against time, where 'F' is the fractional energy market share, shows a cyclic pattern of rise and fall

FIGURE 32 - MARKET SHARES

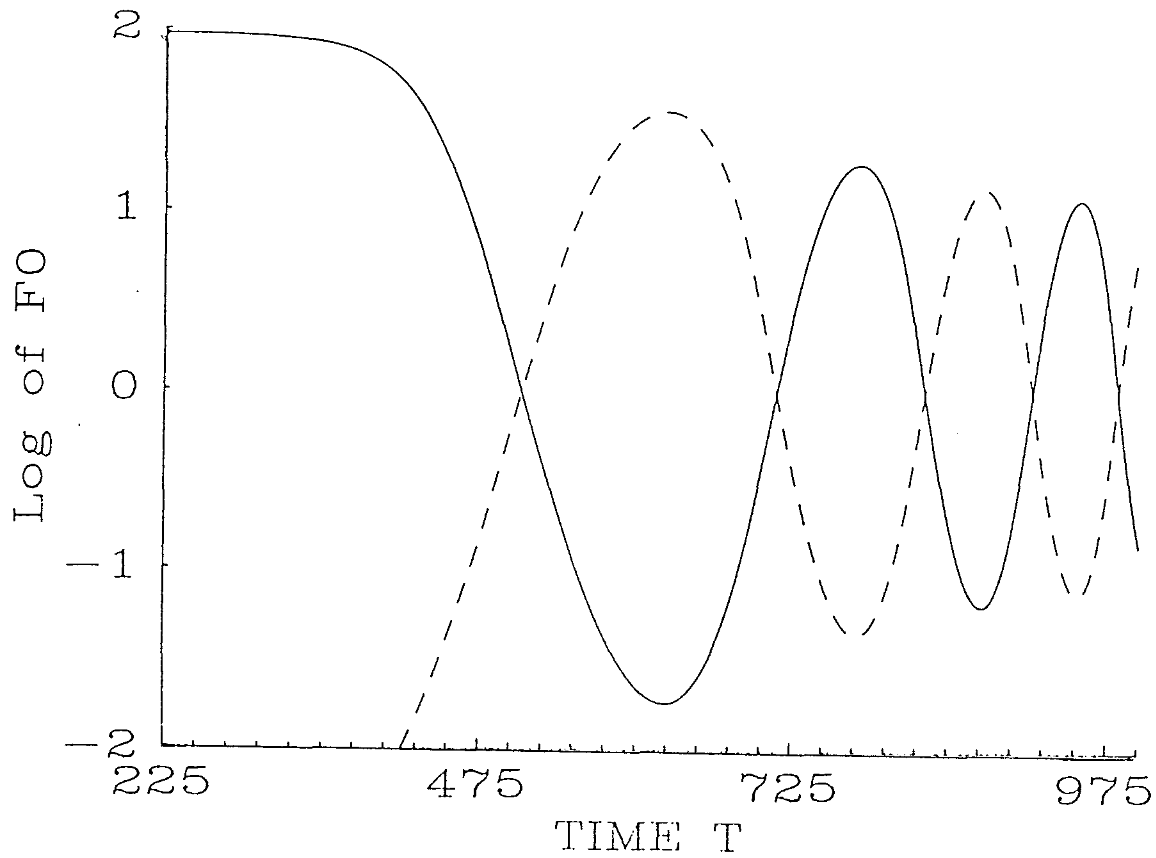


FIGURE 33 - ENVIRONMENTAL STOCK RESOURCES FOR THE ENERGY SUPPLY SECTOR

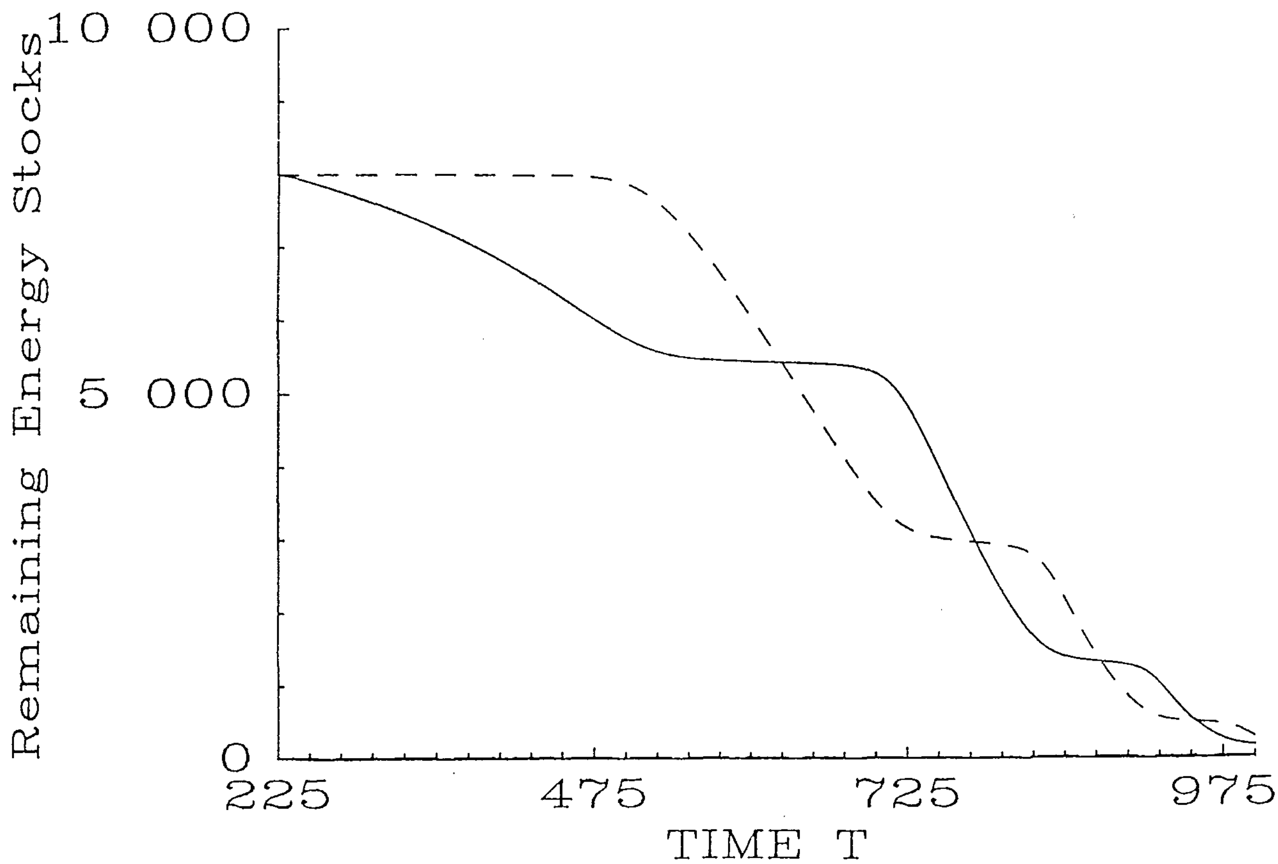
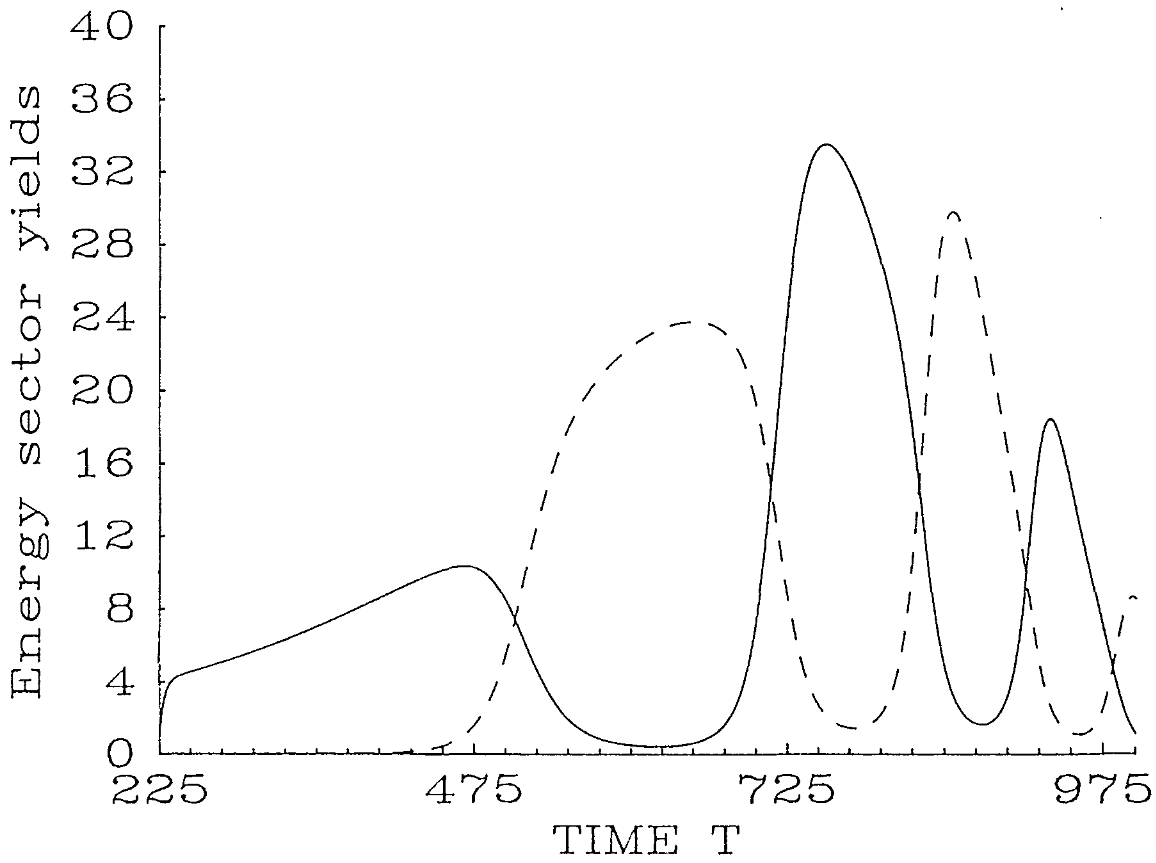


FIGURE 34 - YIELDS FROM THE ENERGY REFINING INDUSTRIES



between the two stock sectors. The first sector dominates the beginning of the run because its Inceptdate is prior to the Inceptdate of the second sector. As soon as the first sector begins to show a decrease in market share, the second sector begins to show a rise. This trend continues with the second sector increasing at the expense of the first sector. They meet at the crossover point, which is the zero level on the graph, corresponding to exactly 50% of the market share each. After the crossover, the first sector declines further, to finally flatten out at the same time that the second sector rises to reach its plateau. Hereafter, the trend is reversed, because the first sector now starts to gain market share, but to the detriment of the second sector, until the first sector has risen to its peak, and the second sector fallen to its low, both crossing at the 50% mark again.

And so the cycle continues, with each sector in turn dominating the energy market share at the expense of the other sector. It is a zero sum gain situation, in the sense that what one sector gains, the other sector must lose.

A point of interest is the decreasing time period between each successive peak of both sectors (Figure 32). There is also a decreasing swing in amplitude between a peak and a trough, over time.

The depletion of resources (Figure 33) is logically consistent with the pattern of the market share. When a sector is dominant, then its stock resources become depleted at a much faster rate than when it has only an insignificant market share.

Similarly, the energy yields are in harmony with the market share. The sector actively dominating the energy market produces far more energy than the sector which is dominated, (Figure 34).

Case 2. Equal Availabilities but different Accessibilities.

The Availability of both sectors is assigned 8000 units, as in Case 1, but the Accessibility of the first sector is assigned 5, half the value of the second sector (10).

The graph (Figure 35) of log F/(1-F) compares very differently from the associated graph (Figure 32) of Case 1. Instead of showing a cyclic pattern of rise and fall, it shows a domination of the energy market by the second sector for most of the time period of the simulation run. This domination, however, comes to an abrupt halt near the end of the run when the first sector makes a sudden comeback. Simultaneously, there is a rapid depletion in the remaining stock resource of the first sector, from nearly its full initial value, to almost zero (Figure 36), and a huge increase in its energy output (Figure 37). This energy yield resembles a 'spike', the magnitude of which is in the order of 10 times the maximum energy yield of the second sector.

FIGURE 35 - MARKET SHARES

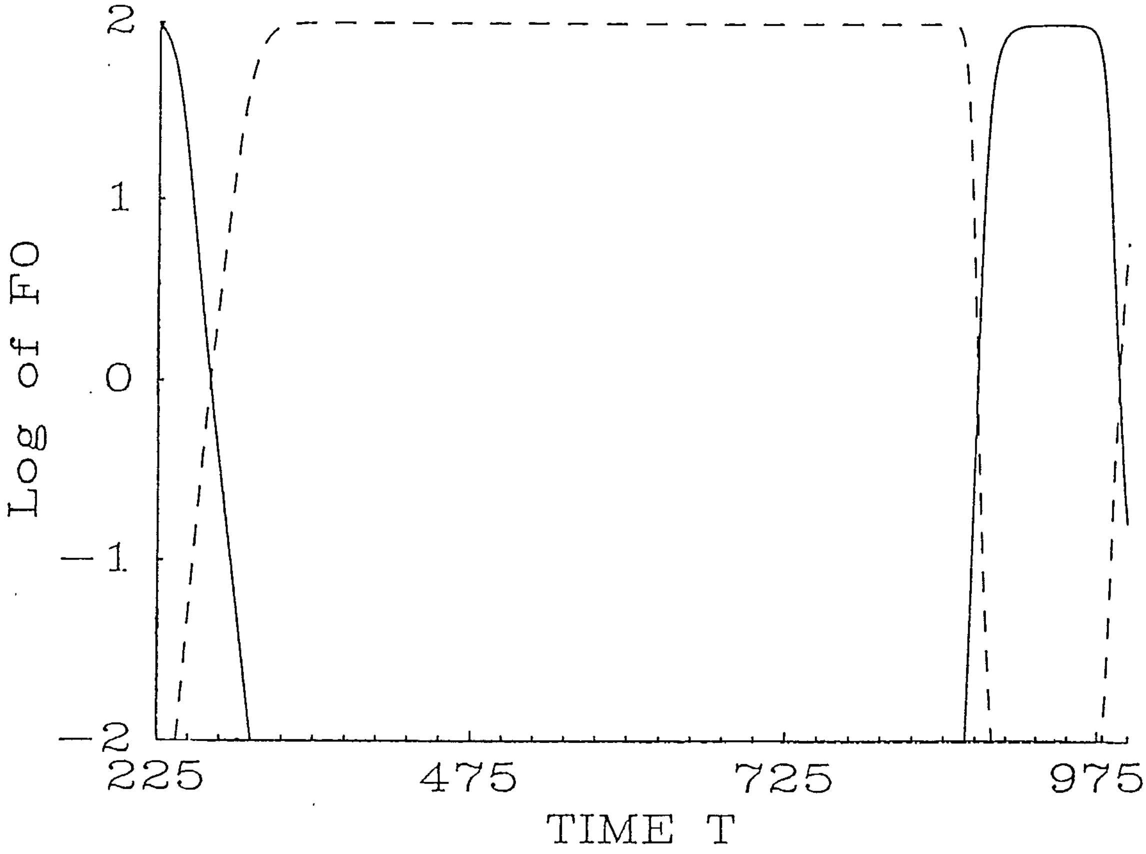
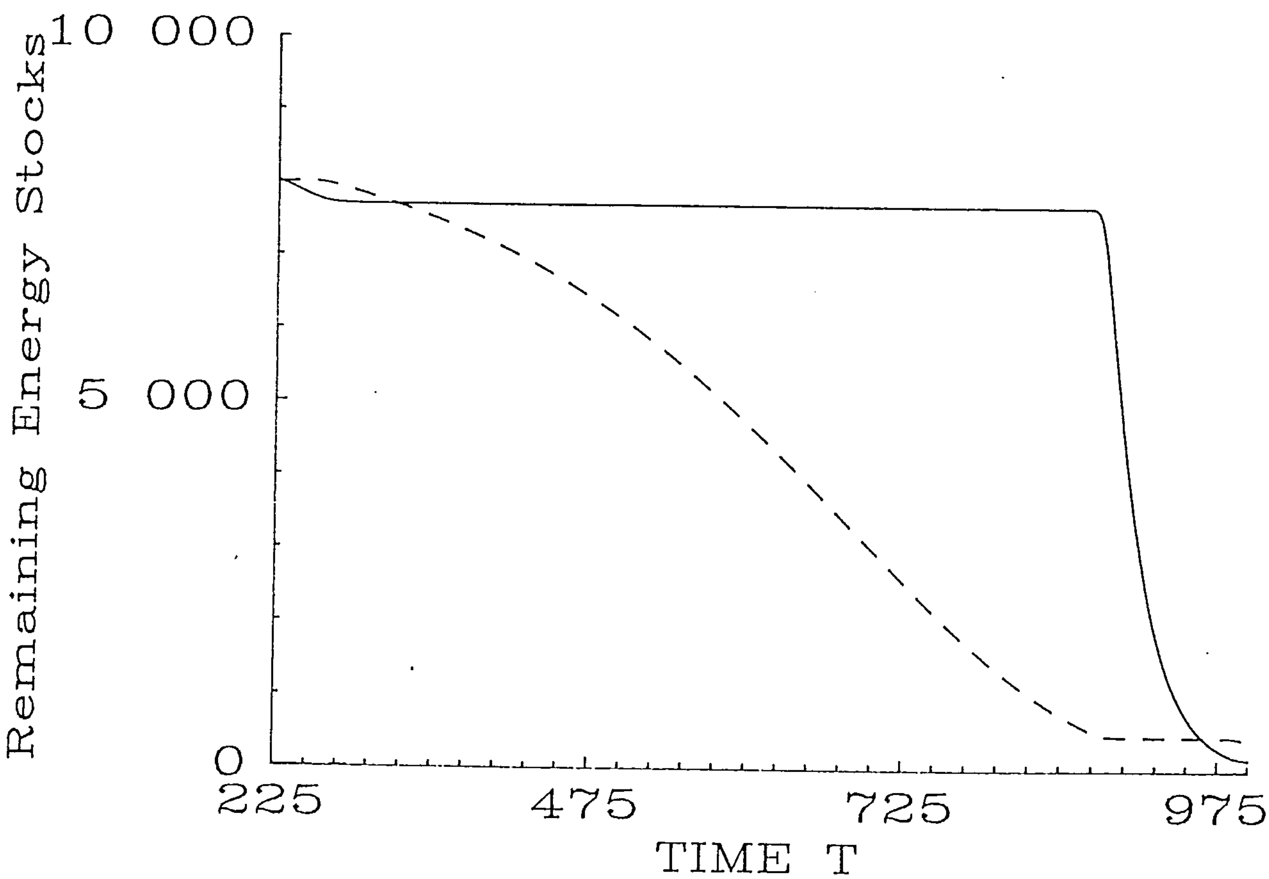


FIGURE 36 - ENVIRONMENTAL STOCK RESOURCES FOR THE ENERGY SUPPLY SECTOR



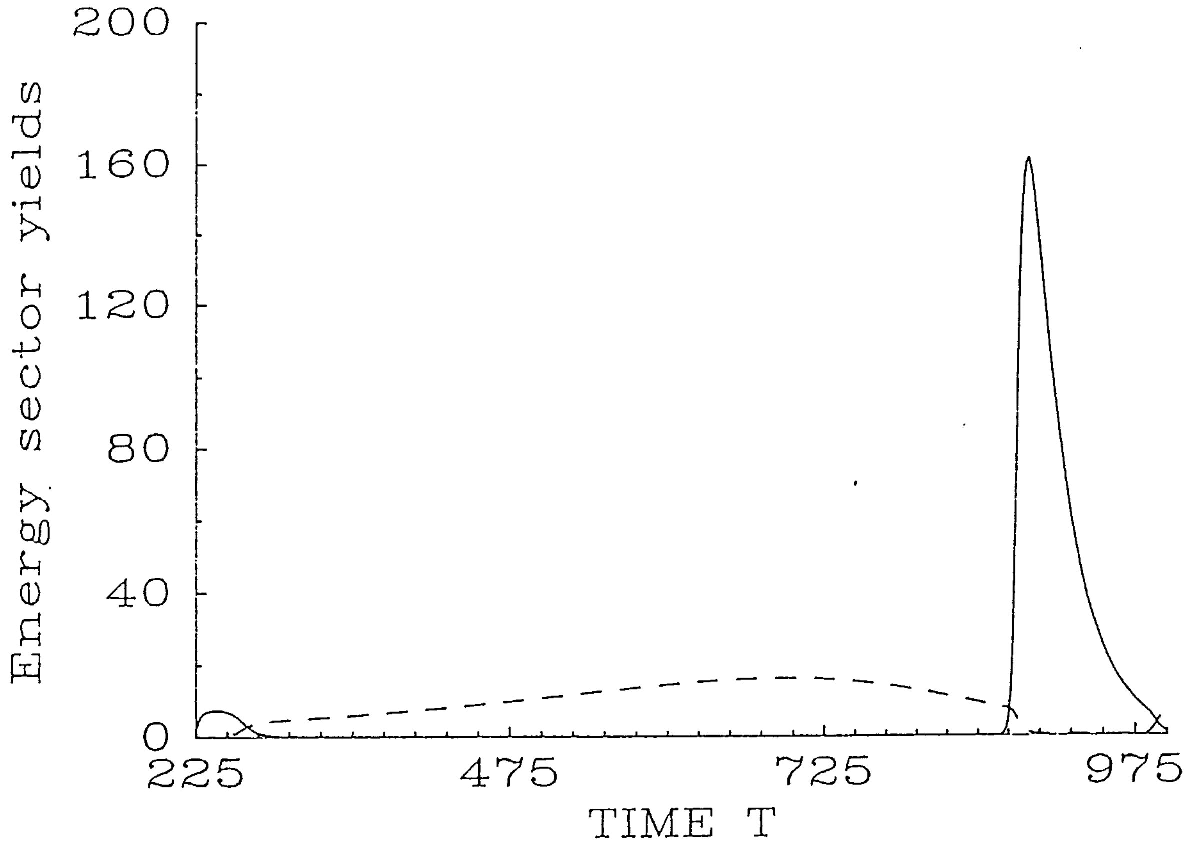


FIGURE 37 - YIELDS FROM THE ENERGY REFINING INDUSTRIES

Following the energy 'spike', both the sectoral remaining stocks are near zero. The 'spike' is the result of using almost the entire stock resource of the first sector in a relatively short space of time.

Case 3. Equal Availabilities but reversed Accessibilities.

Very similar, but reversed results, are obtained if the Accessibilities of Case 2 are reversed in order, (Figures 38,39,40). Letting the first and second sectors assume Accessibilities of 10 and 5 repectively, the graphs of Case 3 have the same characteristics as Case 2, except the first sector replaces the second sector. One obvious difference, however, is the lack of the initial 'settling' period, because in Case 3, the first sector is the dominant sector, therefore it does't become displaced by the other sector at the early stages of the run. This slight temporal difference is carried through the whole run, with the effect of a small time displacement evident in the remainder of the graphs. In effect, the only difference between Cases 2 and 3 is a reversal of the Inceptdates for the two stock sectors. In Case 2, the second sector is the dominant sector, while the first is dominant in Case 3.

7.1 What is the significance of these results?

The simulation modelling of only two energy stocks suggests that, in a two horse race, each sector can cyclically swing from a level of market insignificance to market domination, and back, if the Accessibilities of both sectors are similar. But when the sector Accessibilities are very dissimilar, then this cyclic pattern is not maintained. There appears to be an enormous 'boom' in the energy output of the sector with the smaller Accessibility, followed by a 'bust'. It is as though an energy bomb exploded, signalling a total resource depletion. This energy increase must somehow be absorbed by the socio - economic sector.

In order to avoid the disruptions inevitable from an energy impulse produced by two stock resource sectors of widely differing Accessibilities, the sectoral Accessibilities must be of a similar magnitude. If the Accessibilities are widely differing, then this will cause a state of imbalance, resulting in almost total stock resource depletion in a short space of time, and a correspondingly rapid rise in the energy output of one sector, likened to an energy 'spike'.

However, this conclusion may not be applicable to the real world if there are more than two stock resources in use. But it is a hypothetical base for

FIGURE 38 - MARKET SHARES

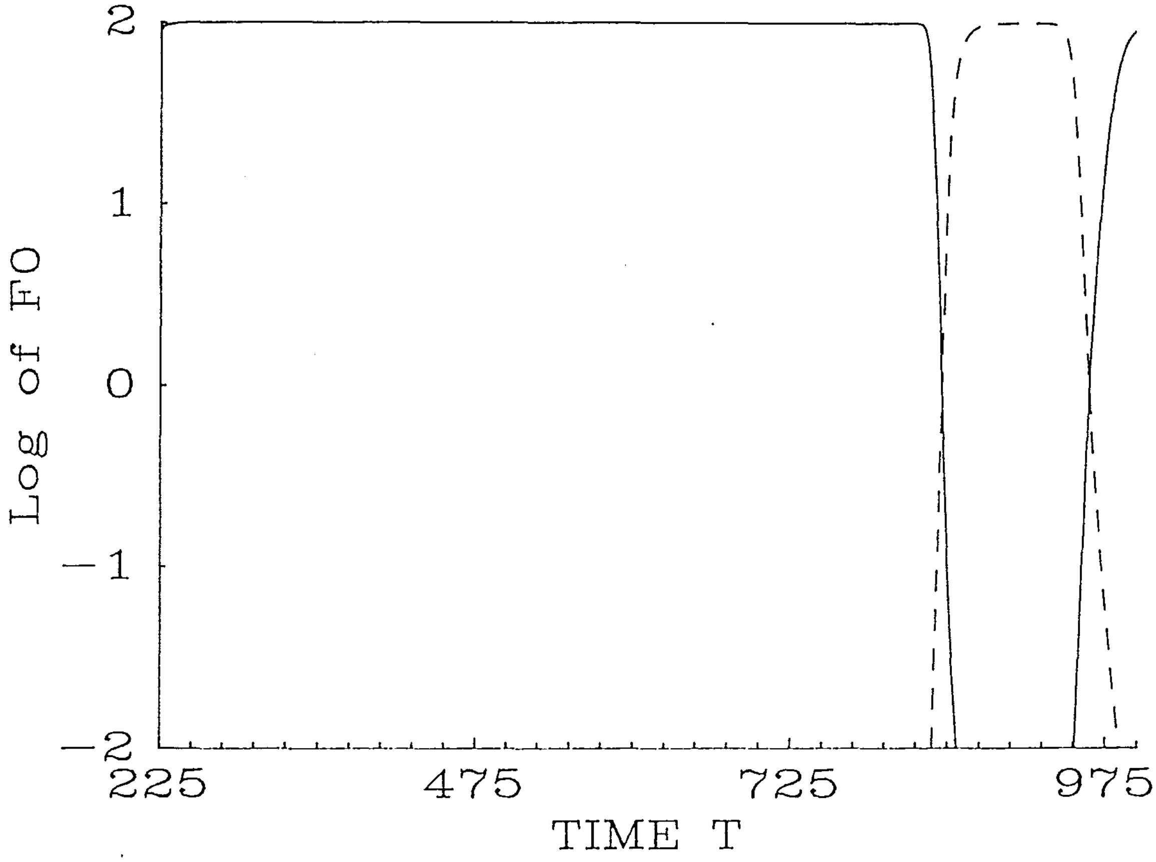


FIGURE 39 - YIELDS FROM THE ENERGY REFINING INDUSTRIES

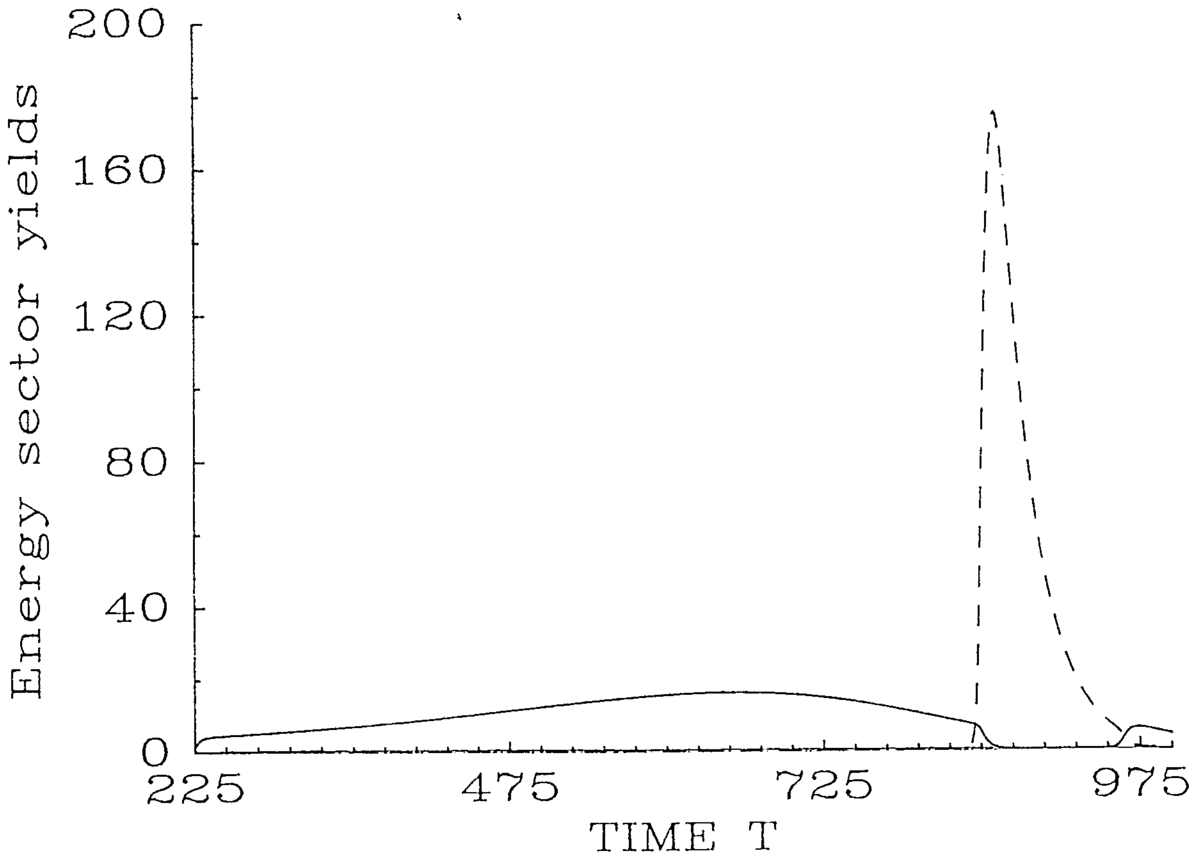
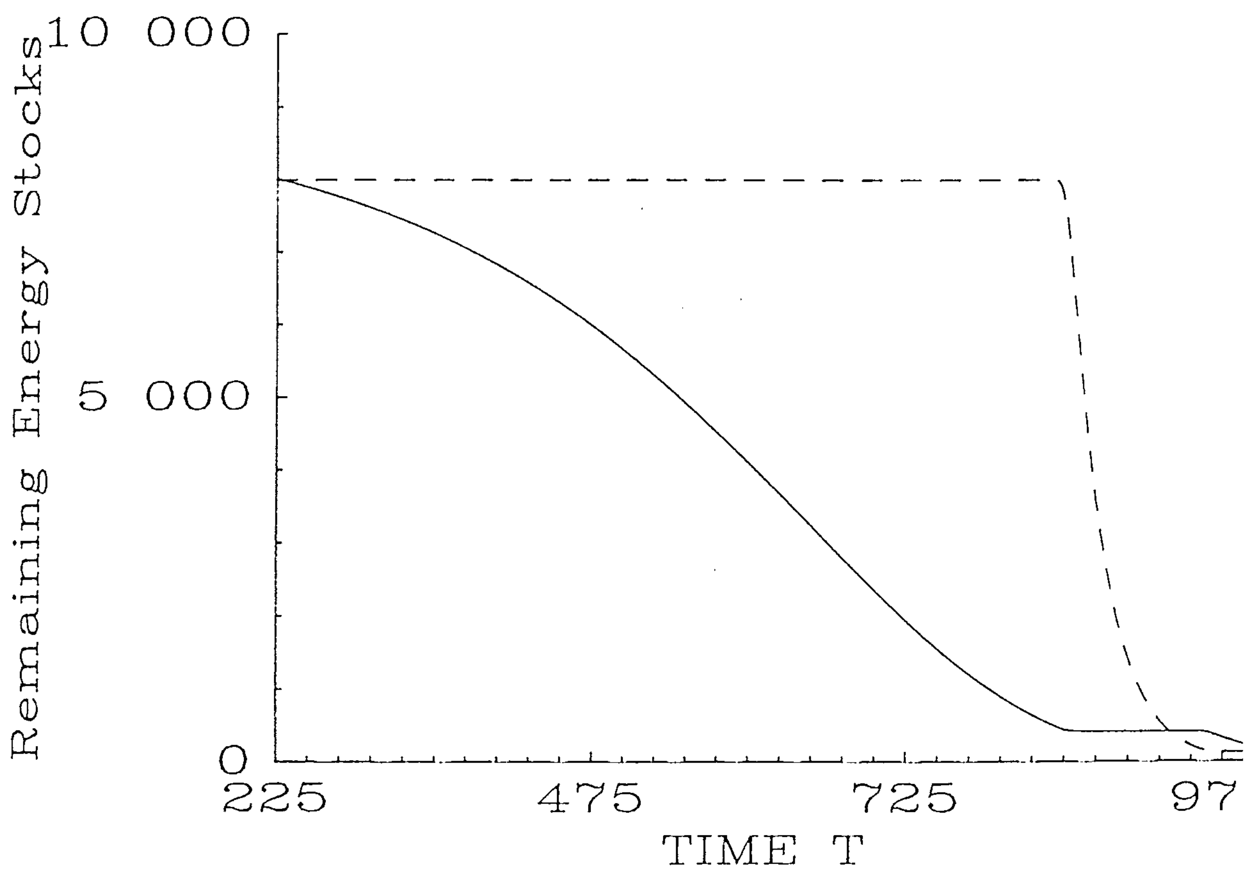


FIGURE 40 - ENVIRONMENTAL STOCK RESOURCES FOR THE ENERGY SUPPLY SECTORS



an expanded understanding of the complex web of dynamics between energy and society.

Chapter 8

Two sectors - 1 flow source, 1 stock resource.

The model representation of Figure 3 is altered for this chapter by eliminating 2 of the 3 energy stock sectors, leaving only 1 stock sector and the flow source. This is modelled by the flow source incepting at the start of the run, with the stock sector inception date just one year later.

Figures 41 and 42, in which the Availability of the stock sector is halved from 20,000 to 10,000 respectively (but the Availability of the flow source is constant at 9898.9), show that the domination of the energy market depends to a large extent on the relative Availability of the stock sector to the flow source.

Figures 41, 43 and 44, where the Accessibility of the stock sector is changed from 25 to 30 to 20 respectively (but the Accessibility of the flow source is fixed at 10), illustrate that the relative Accessibility of the stock sector and flow source has a significant impact on the market shares over time.

When the Availability of the stock sector is decreased from 10,000 (Figure 42) to 1,000 (Figure 45), all other parameters equal, then the stock sector is actually 'revisited' after its initial cycle. This is an important feature because it means that with the passage of time, what may have seemed an unviable proposition becomes viable at a later date, and a formerly discarded energy sector is revived, if only for a short period. It *again* becomes an alternative energy source. A necessary precondition for a stock sector to be revisited is the non-exhaustion of stock reserves - that is, the Availability of the stock sector must be greater than zero before it can be revisited (Figure 46). One may therefore conclude that the reason for a 'sector submission' is not necessarily a depletion of the flow source or stock reserve of that sector, because Figure 46 shows that the Availability is *not* zero when the stock sector subsides. However, it can be - for example, when a stock reserve is exhausted, then there is no more resource left to refine, and that sector will die.

FIGURE 41 - MARKET SHARES

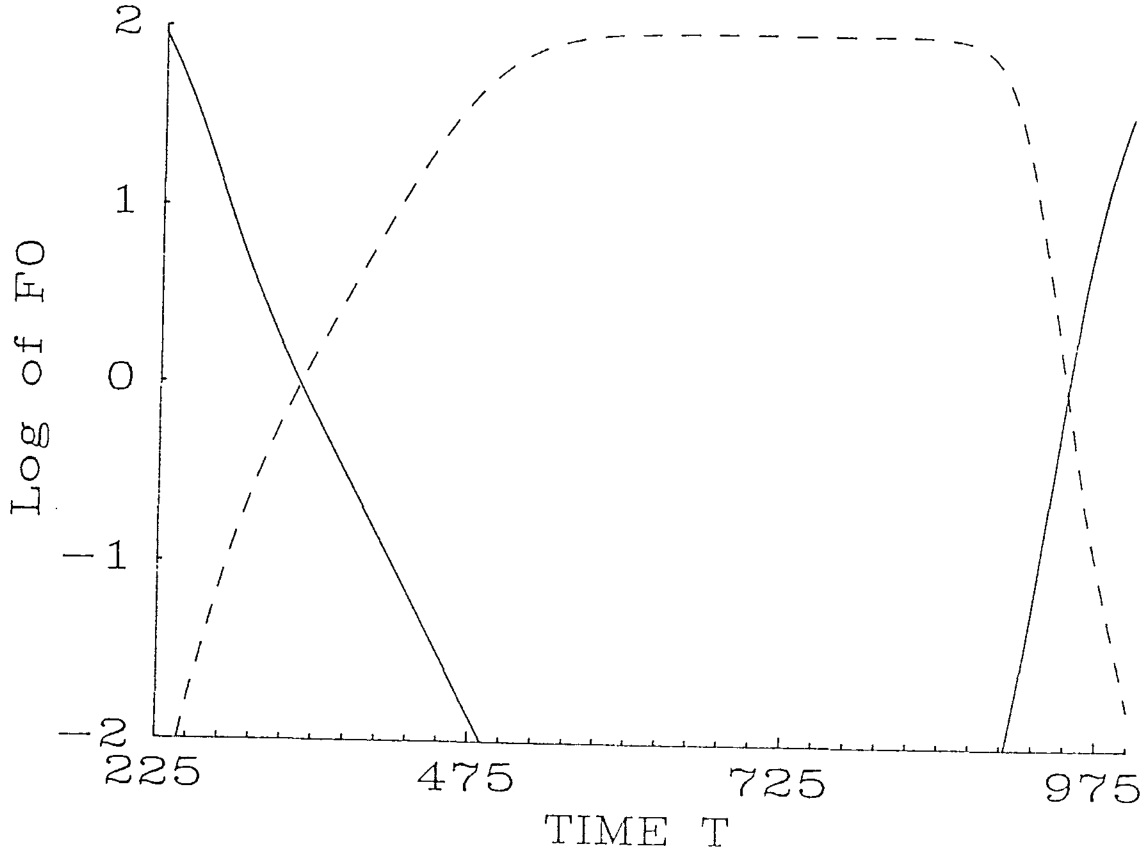


FIGURE 42 - MARKET SHARES

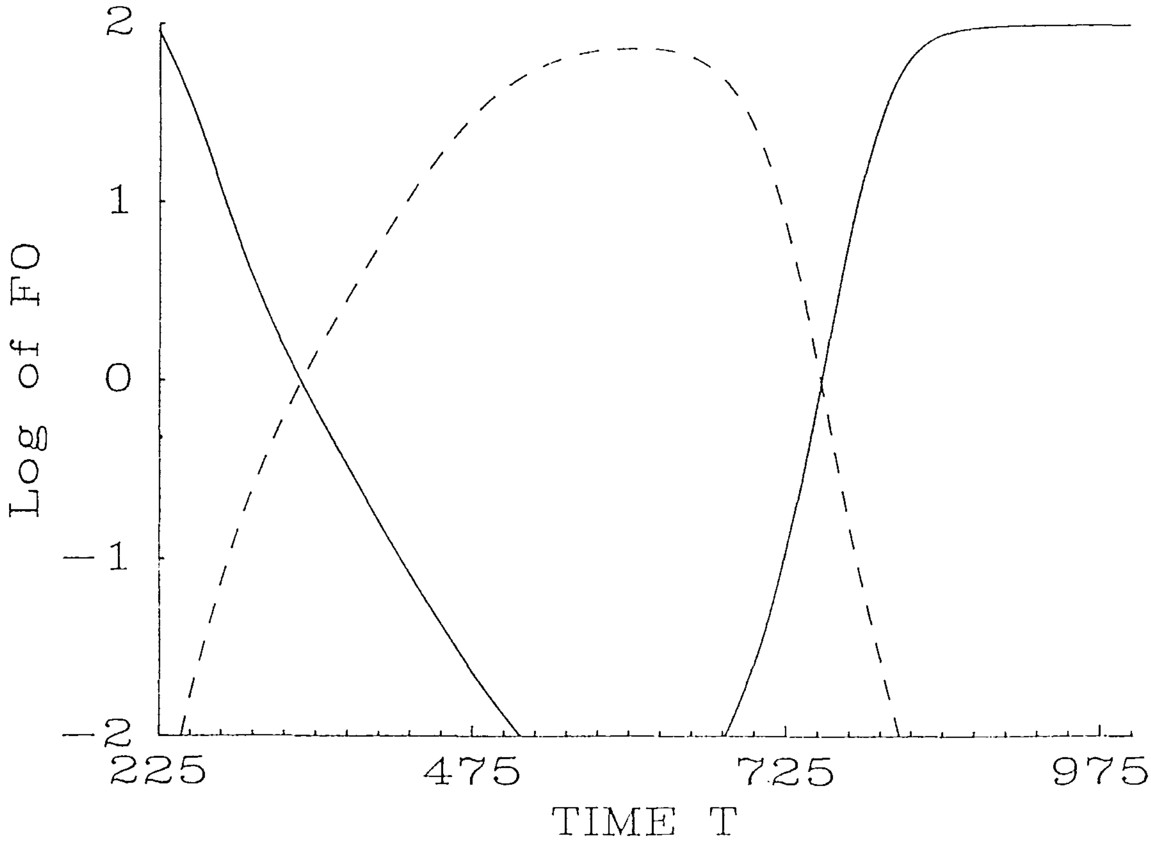


FIGURE 43 - MARKET SHARES

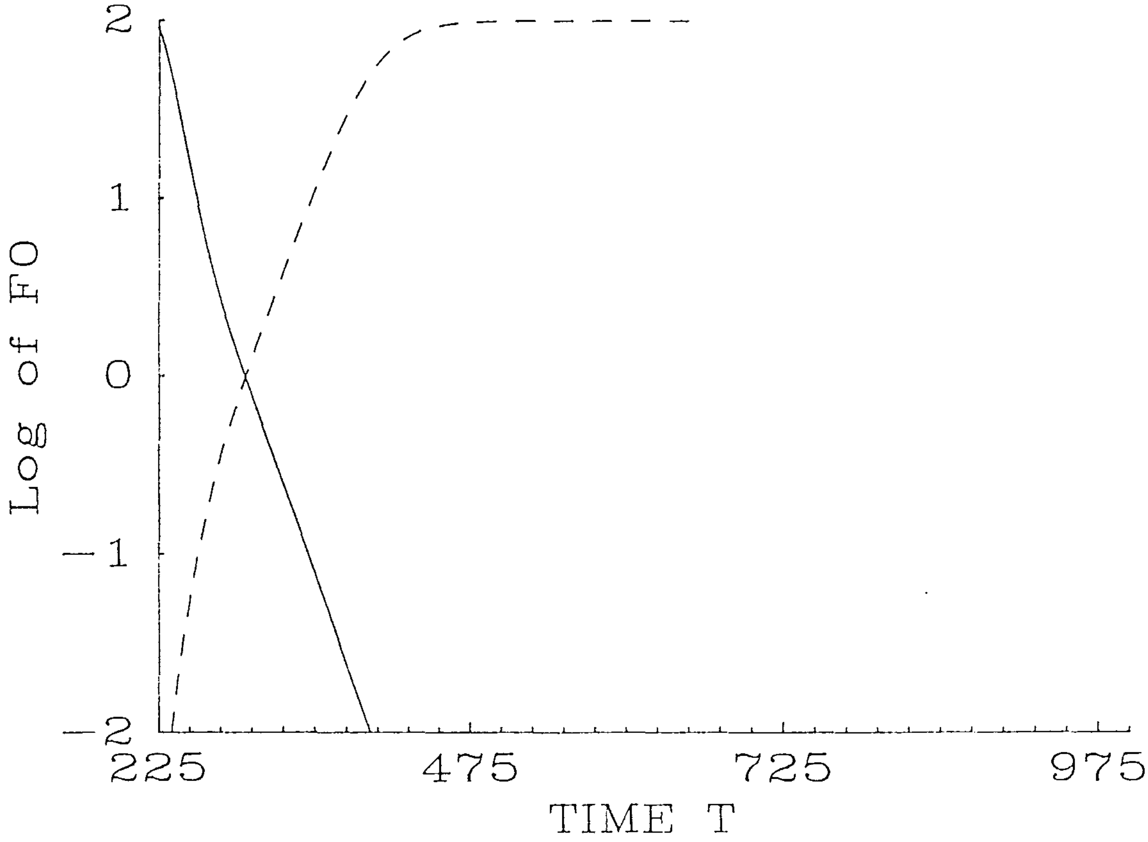


FIGURE 44 - MARKET SHARES

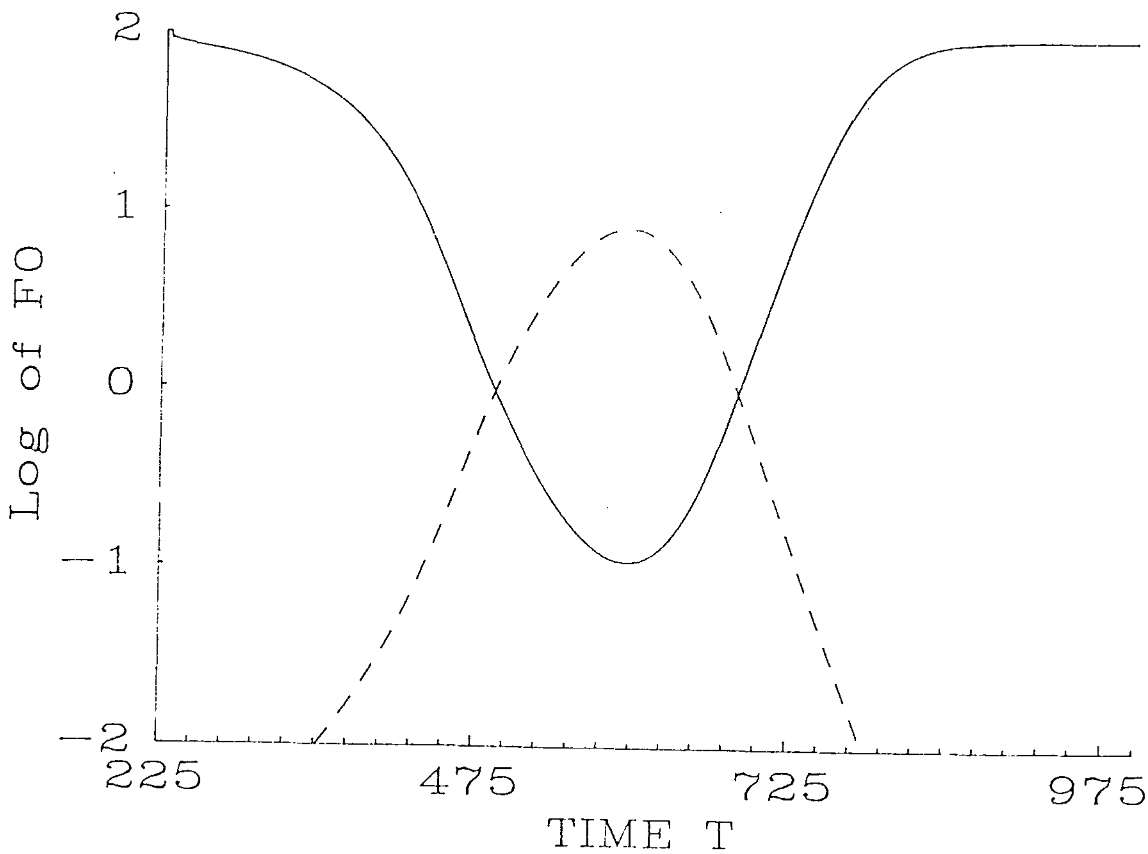


FIGURE 45 - MARKET SHARES

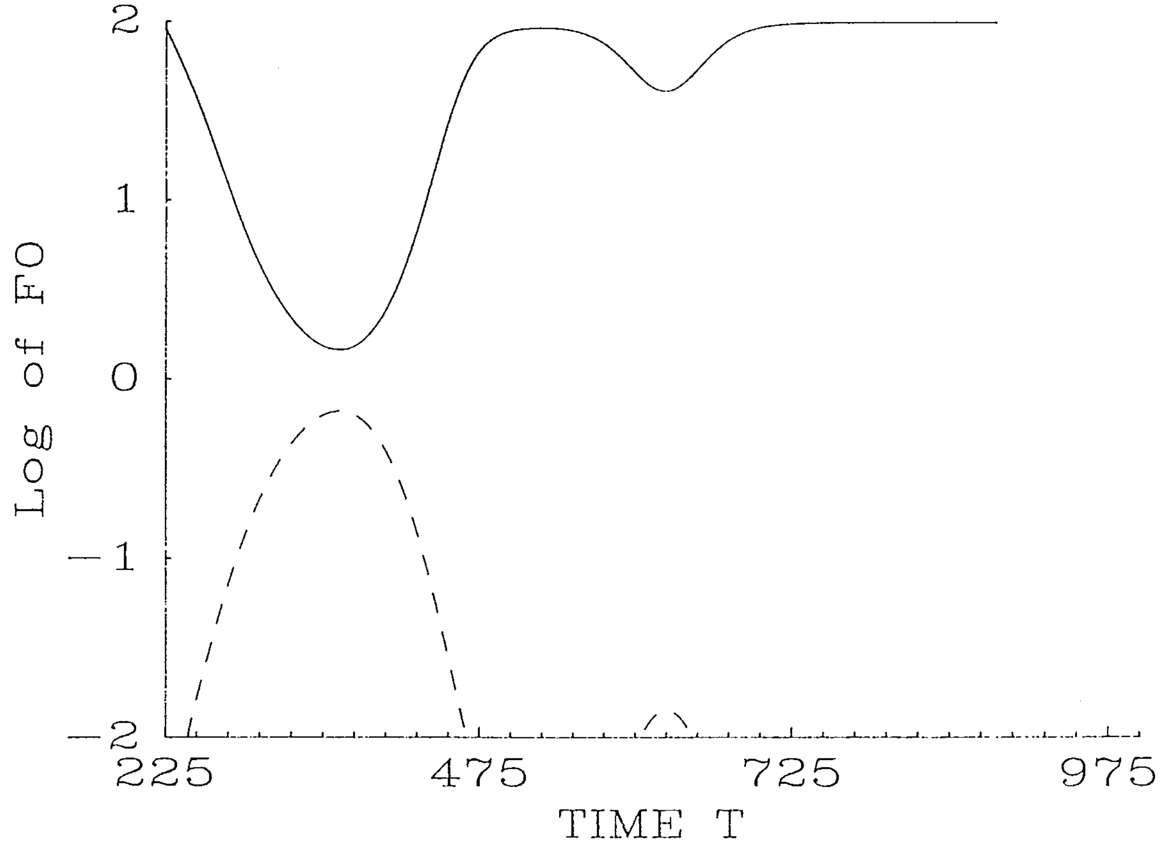
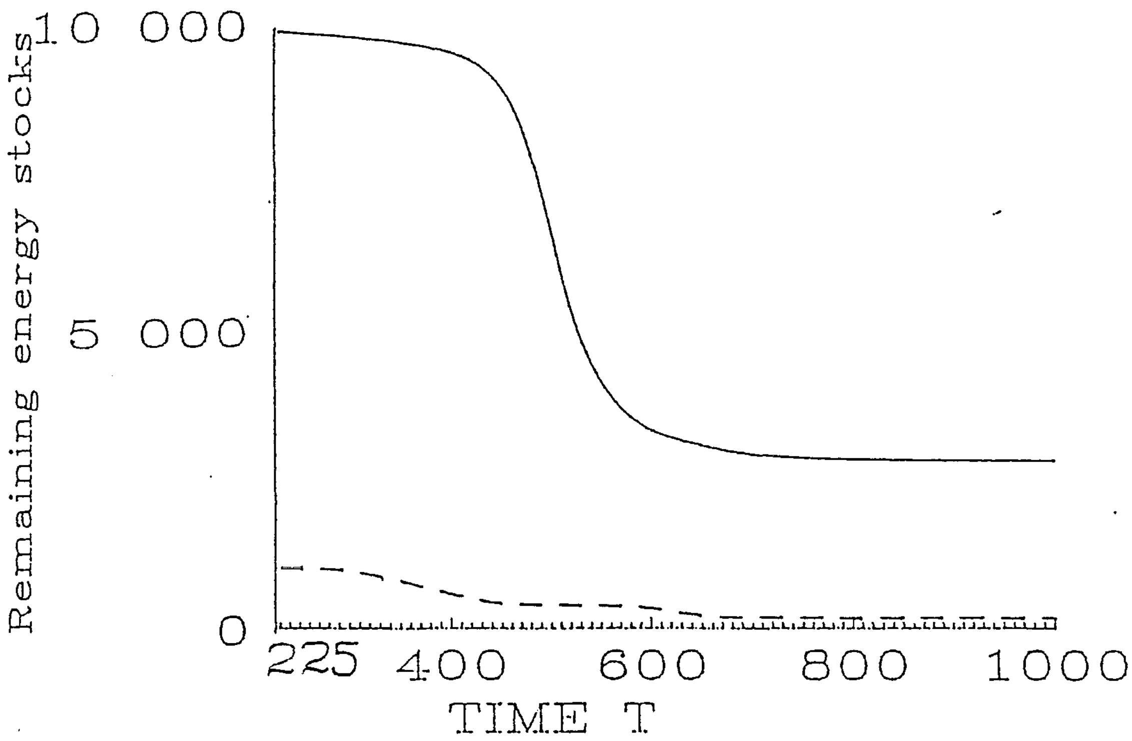


FIGURE 46 - ENVIRONMENTAL STOCK RESOURCE AND FLOW SOURCE FOR THE ENERGY SUPPLY SECTOR



It is noted that the flow source provides an 'infinite' source of energy, but this is strictly rate limited, while a stock resource has no such rate limitation, but once consumed, it is gone forever. Hence the flow source will ultimately win out over the stock resource once the latter is used up, but the stock resource may dominate the energy market for a time depending on the relative Availability and Accessibility parameters.

Chapter 9

Three sectors - 1 flow source and 2 stock resources.

The model representation of Figure 3 is again altered by eliminating just 1 stock sector, leaving 2 stock sectors and the flow source.

Figures 47,48 and 49 show that slightly altering the Inceptdate of the second stock sector by 1, 25 and 5 years respectively from the first stock sector, given that the two stock sectors have identical parameters of Availability (2000) and Accessibility (25), has the effect of amplifying the relative differences in market share, especially between the peak of the second stock sector, and the trough of the first. But they both degenerate at about the same time, when the solar sector takes the market lead.

If the Availability of the second stock sector is now decreased (1000) to half that of the first stock sector,(2000), as in Figure 50, the Accessibilities are equal and there is a 1 year inception time differential, then it is found that the first sector at all times maintains a greater market share than does the second sector, whereas previously, with equal Availabilities, they were fairly evenly matched, although crossed over at 3 points (Figure 47).

If the Availabilities of the 2 stock sectors are now reversed, assigning 1000 units to the first and 2000 units to the second (Figure 51), the result is an accentuation of the curves seen in Figure 47 (recall Figure 47 has equal Availabilities at 2000 units each), promoting a wider gap between the peak of the second stock sector and the trough of the first.

However, it is noted that guideline 2 of Chapter 6 is somewhat in contradiction with this result. If this guideline were correct for 3 sectors, then an increased Availability of the 3rd over the 2nd sector should alter the market pattern - but it doesn't. It only accentuates the reference graph (Figure 47).

The answer to this inconsistency may be twofold. First, the aforementioned guideline was given based on experimental evidence for just 2 stock sectors. There are now 3 sectors. Second, the first of the 3 sectors is a flow source, not another stock sector, and as already pointed out, there are considerable differences between a flow source and a stock resource. These

FIGURE 47 - MARKET SHARES

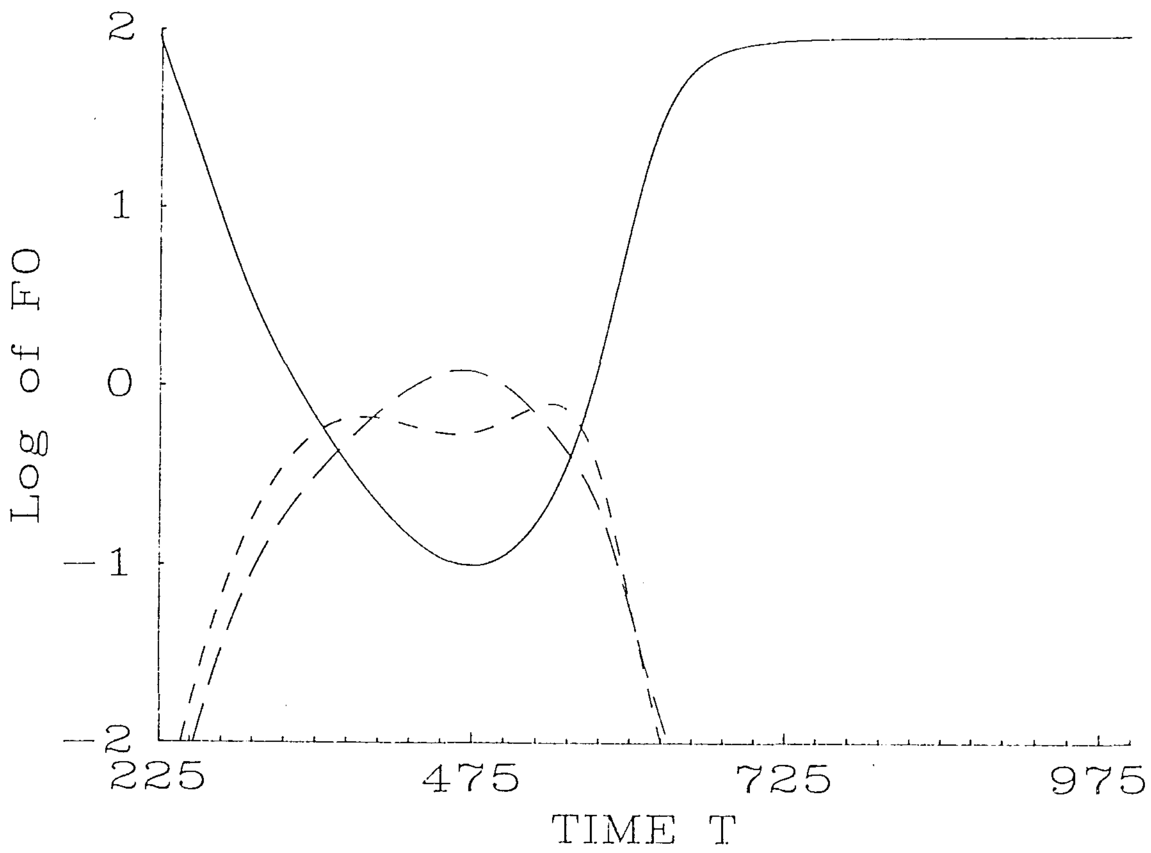


FIGURE 48 - MARKET SHARES

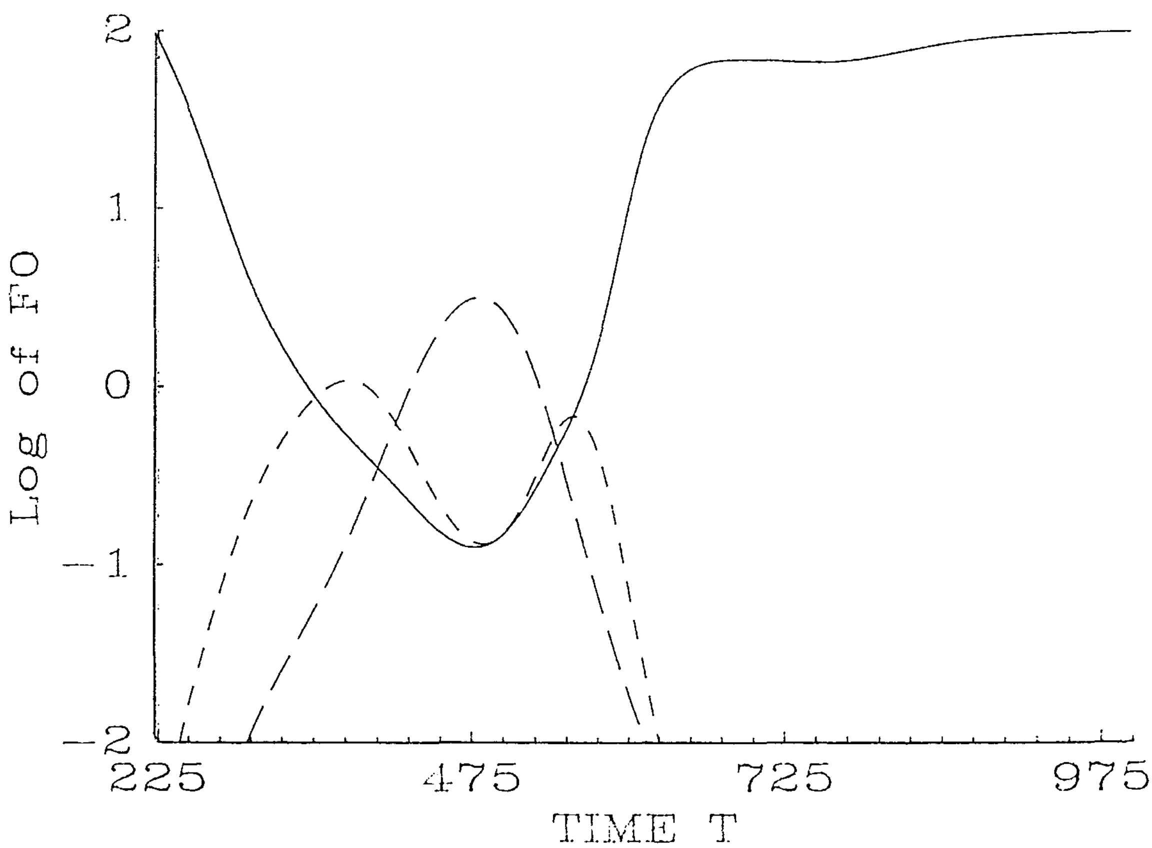


FIGURE 49 - MARKET SHARES

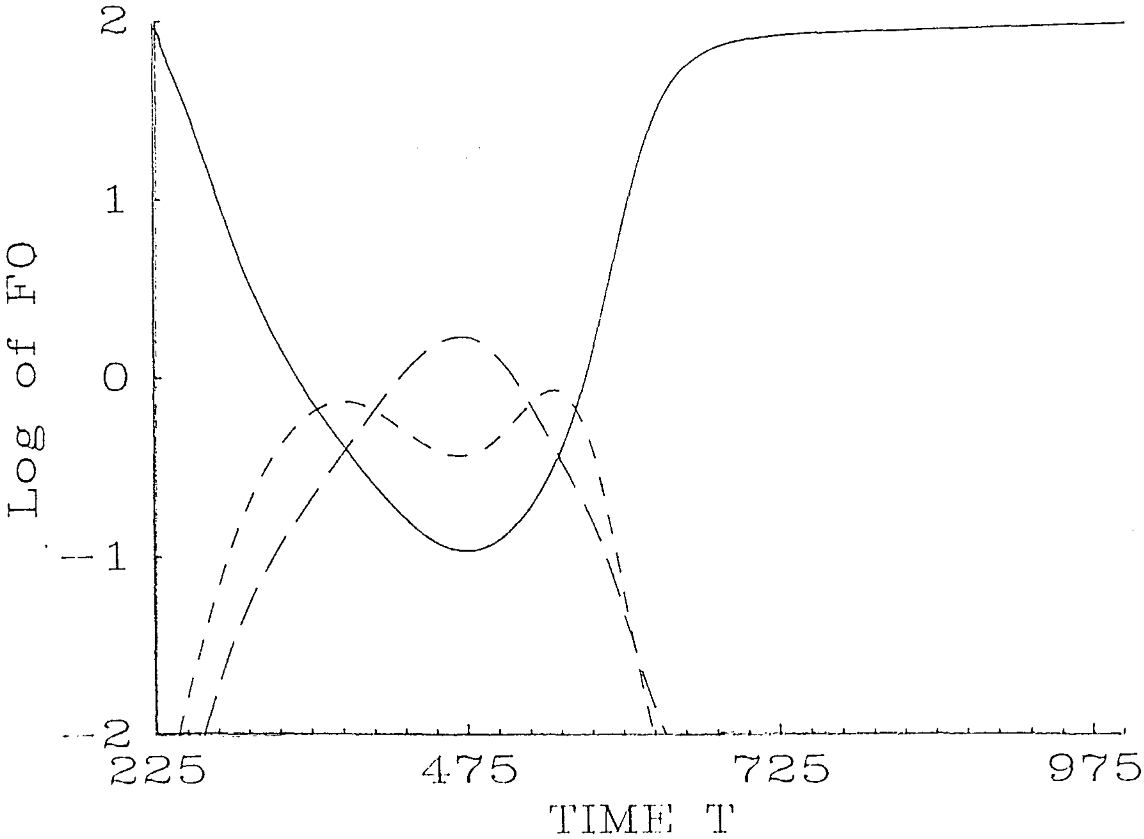


FIGURE 50 - MARKET SHARES

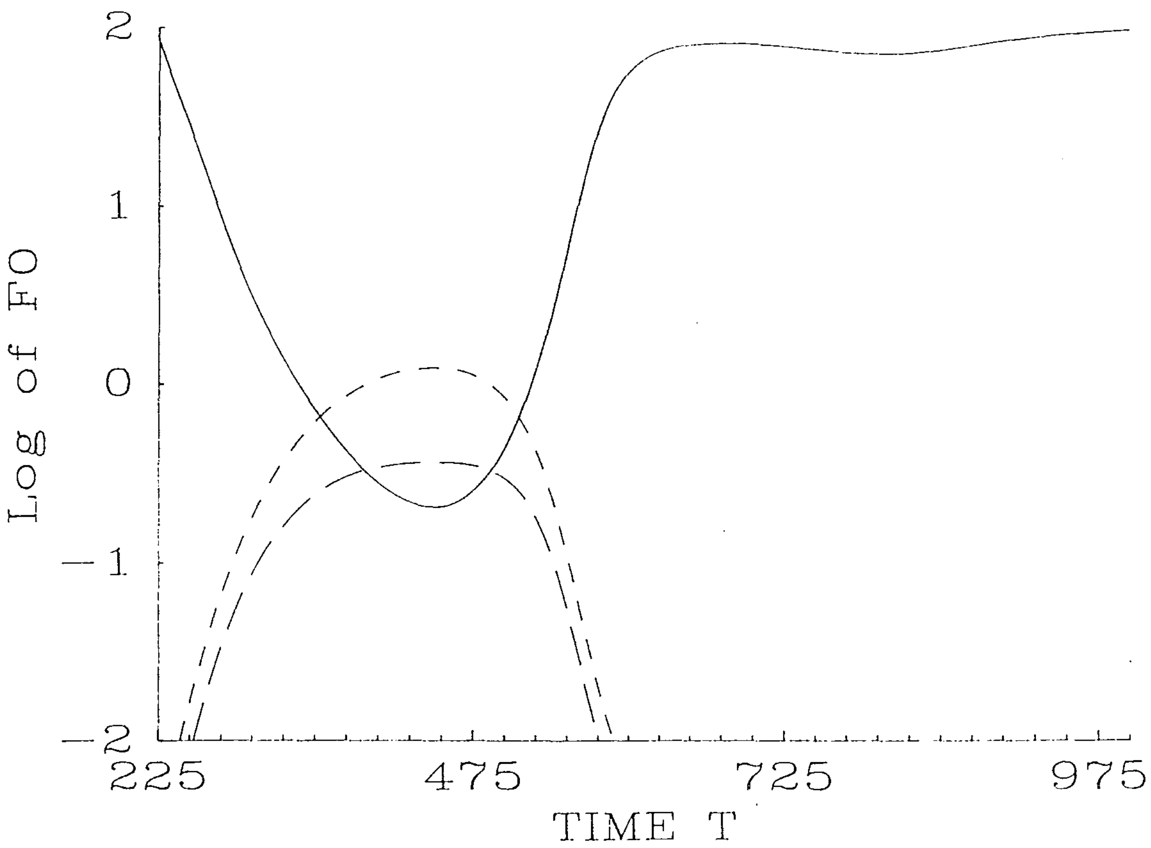


FIGURE 51 - MARKET SHARES

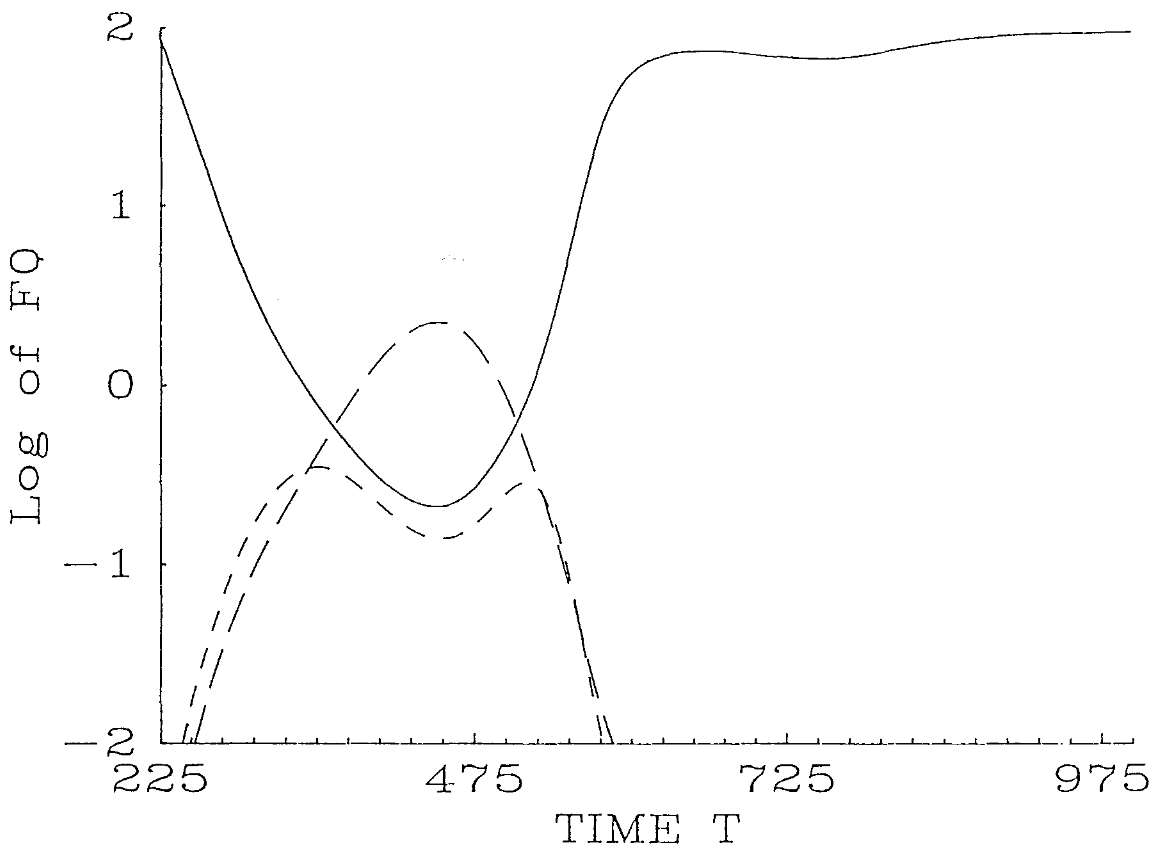
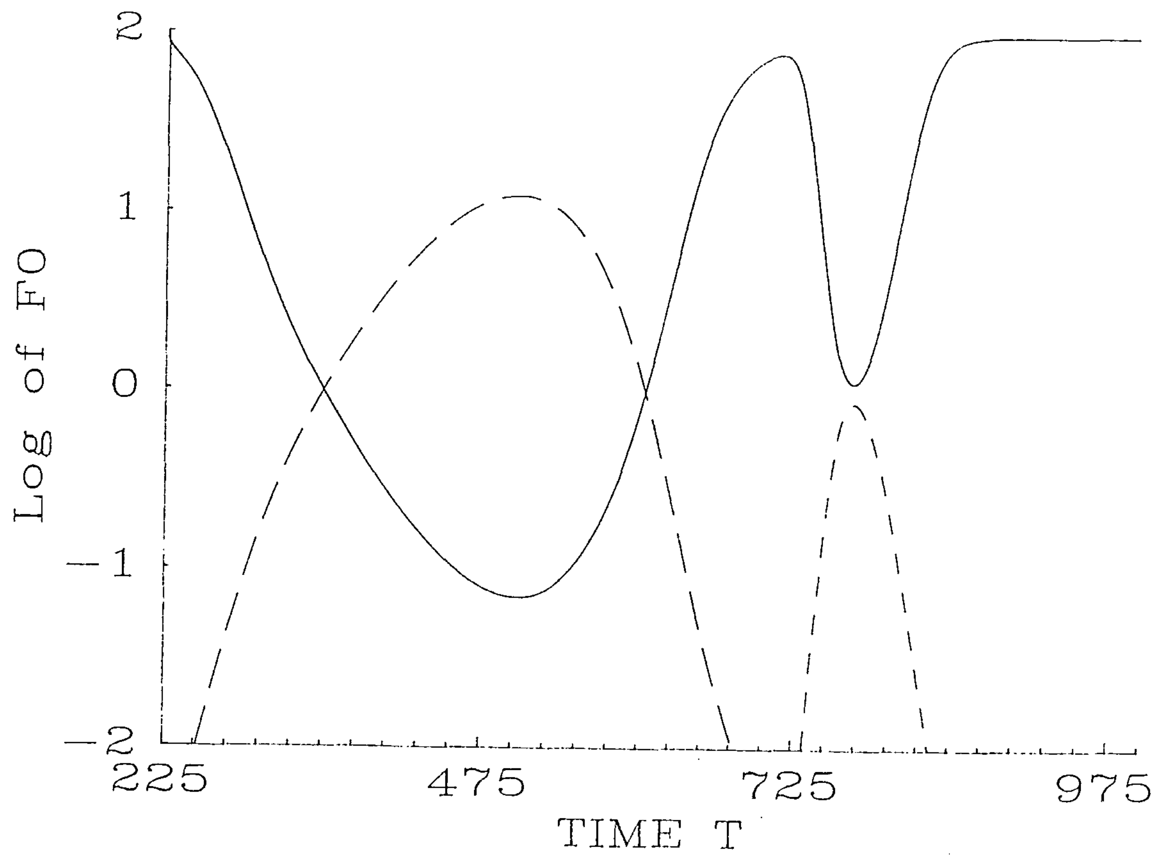


FIGURE 52 - MARKET SHARES



are only suggestions to explain the apparent inconsistency - they have been neither proven nor disproven.

Turning our attention to the Accessibilities, the familiar delay time is observed when the Accessibility of the second stock sector (25) is higher than that of the first (15). When the difference between the Accessibilities is decreased, again, the delay time decreases. This is shown by Figure 52 which differs from Figures 47 to 51 because the *first* stock sector is delayed from coming 'on stream' until after the *second* stock sector has risen and fallen. This delay is caused by the greater Accessibility of the second (25) over the first (15) stock sector.

What is the factor or factors determining the point in time of the second stock sector coming 'on stream'? All that is known so far is that an increased difference in Accessibilities between the 2 stock sectors (with the second sector having the higher Accessibility) results in an increased delay time for the 2nd sector to come on stream.

The best indicator so far is not the energy sector infrastructures, nor their sum, but the energy yield, in conjunction with the Availability ie. the remaining stock resource (Figures 52, 53 and 54). When the energy yield or output of the second stock sector has risen, decreases and is almost zero, then there is a rapid consumption of resources from the first stock reserve, which in turn is refined into fuel and boosts the market share of the first sector. Although not by any means perfect, the decrease in energy yield toward zero of the second stock sector seems to trigger the 1st stock sector, measured by the rapid consumption of resources, and rise in market share.

FIGURE 53 - ENVIRONMENTAL STOCK RESOURCES FOR THE ENERGY SUPPLY SECTOR

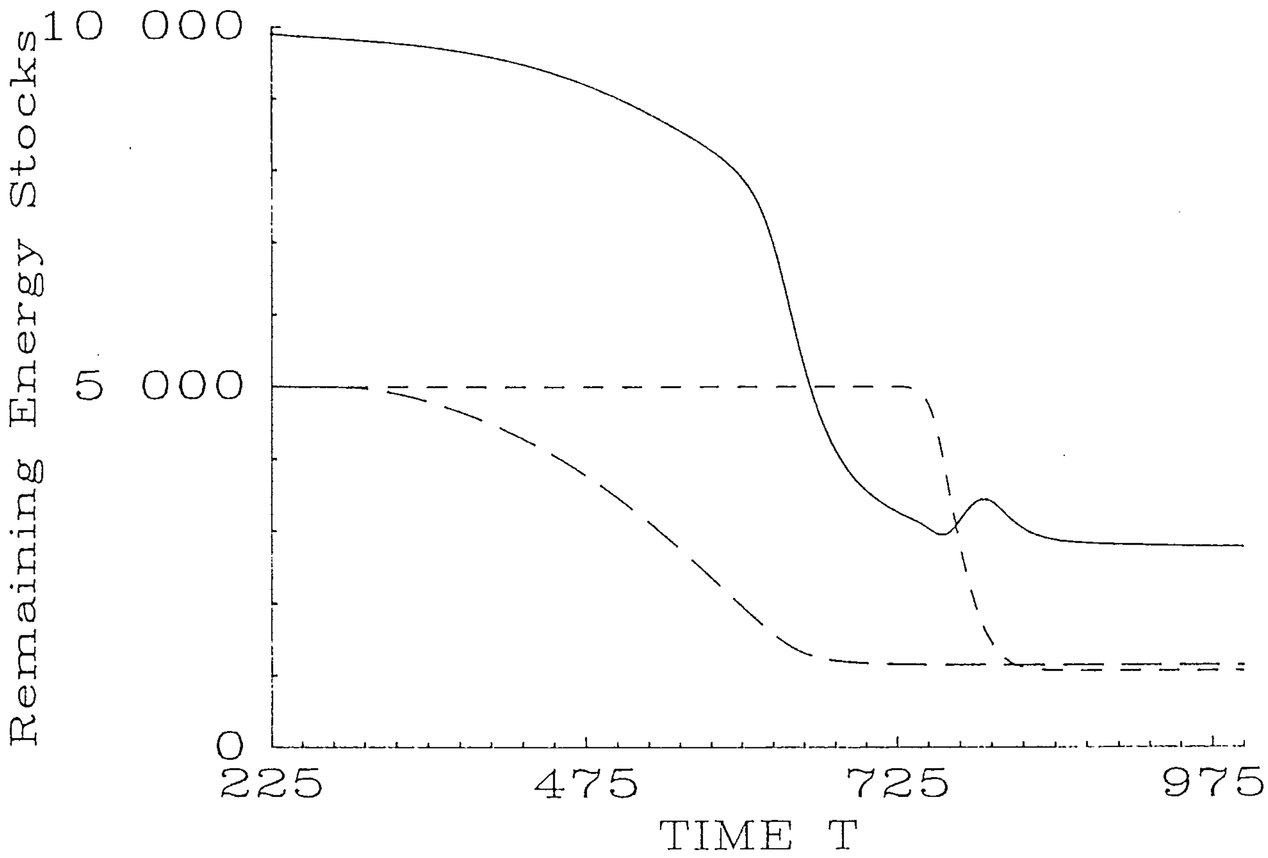
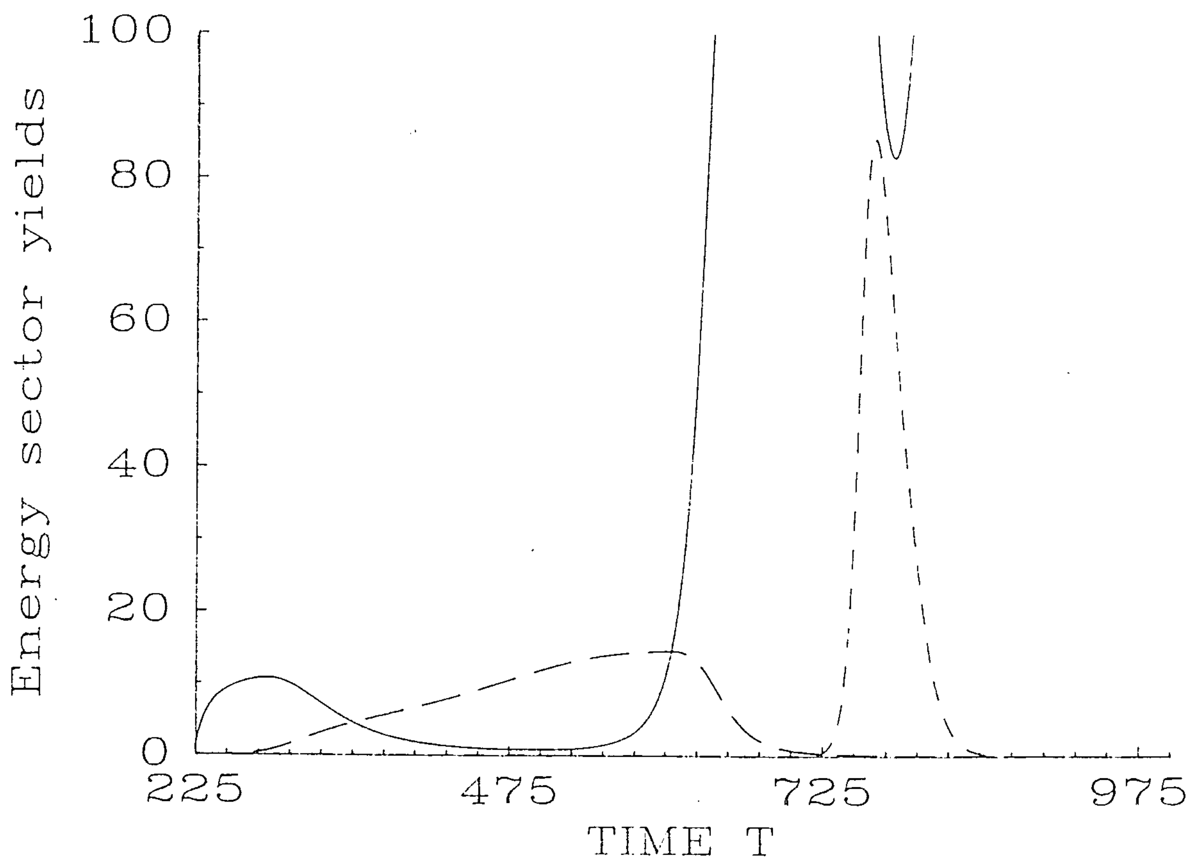


FIGURE 54 - YIELDS FROM THE ENERGY REFINING INDUSTRIES



Chapter 10

Simulation data.

The 4 primary energy sectors which the author has simulated from 1850 to circa 1970, correspond to wood, coal, oil and natural gas. Marchetti[2] has collated data on each of these primary energy sources, and graphed them (Figure 55) over time as F/(1-F), on a log(10) scale, where F is the fraction of the energy market. Marchetti has proposed a logistic type curve, shown by the solid lines on the graph, while the statistical data is represented by the wriggly lines. The graph portrays world fractional energy substitution.

In order to simulate the patterns of Figure 55 using the dynamic energy systems model of Figure 3, discussed in Chapters 3 and 4, it was necessary to use fractional Accessibilities because of the sensitivity of the plots to changes of 1 or greater. Simulating the data at an inception level of 1% produced some 'not well behaved' graphs of the sum of the energy sector infrastructures and newinfrastructures. The inception level is the percentage of existing total energy yield which a new sector is endowed with upon its Inceptdate. This initialises, or 'kicks off', the new sector, but because it is a discrete jump, similar to a step function, it may cause undesirable transient effects if the level is too great. The program was therefore changed from an inception level of 1% to 0.1%. But because of this, the Inceptdates had to be changed as well, in order for each new sector to incept at the 0.1% level, *but reach the 1% level as if they had incepted there.* This was accomplished through a process of trial and error. Table 10.1 shows the set of data parameters which were found to give the best fit to the historical data accumulated by Marchetti.

	Availability	Accessibility	Inceptdate
Biomass	9898.9	10	0
Coal	26,000	21.5	85
Oil	28,000	23.5	210
Gas	30,000	24.0	233

Table 10.1: Simulation parameters for 0.1% inception level.

FIGURE 55 - MARCHETTI [2] WORLD FRACTIONAL ENERGY SUBSTITUTION

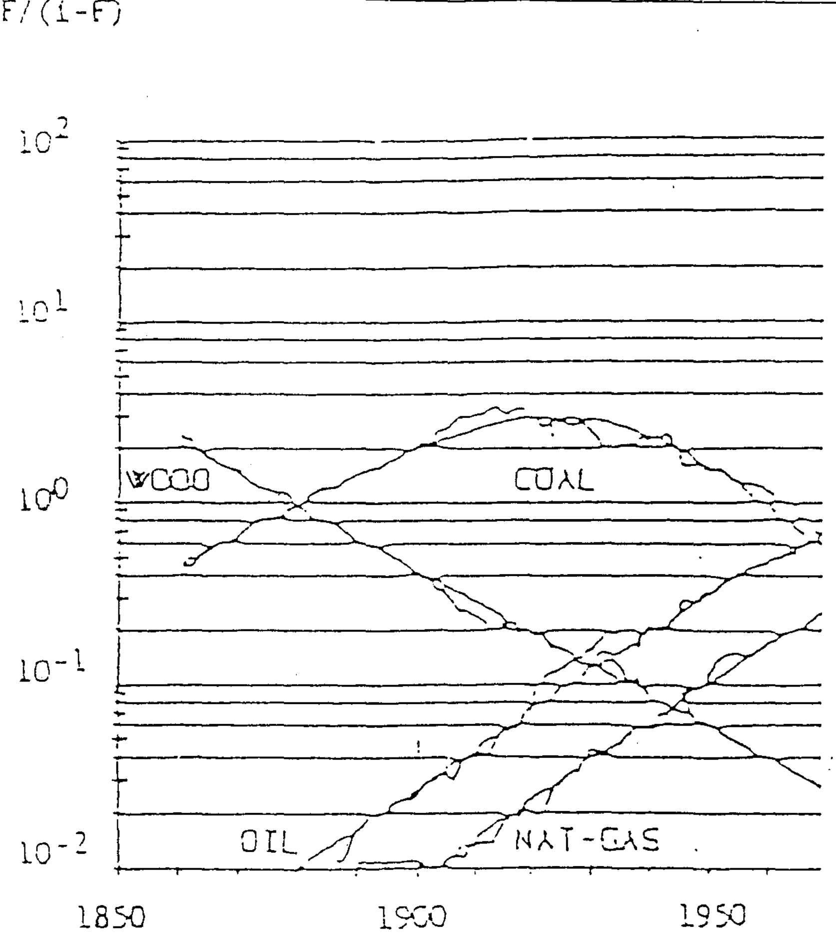
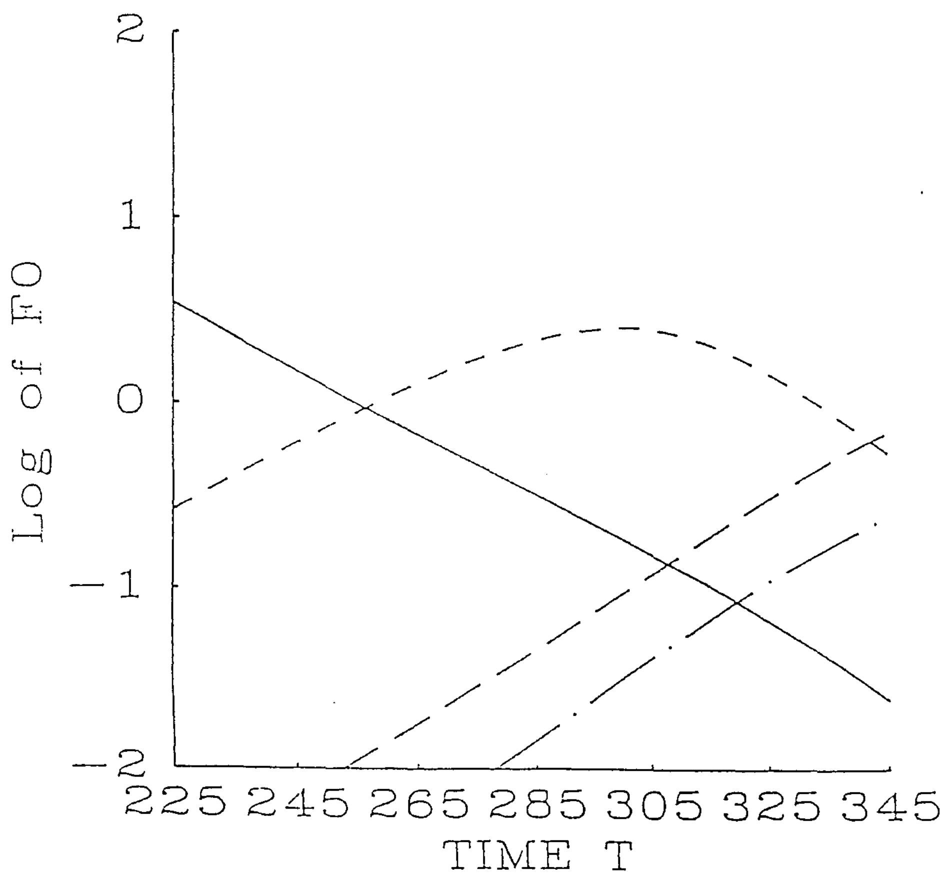


FIGURE 56 - MARCHETTI DATA SIMULATION - 0.1%



The results are quite satisfactory. The graph of the market shares (Figure 56, where FO = F/(1-F)), closely resembles that produced by Marchetti, and the graphs of the sum and absolute sum of the energy sector newinfrastructures are far smoother and more well-behaved, (Figures 57,58,59,60). But to be totally satisfied that there is no real difference between the programs with the 1% and 0.1% levels, the time scale was expanded to 1000 iterations, corresponding to 1000 years. Both programs and their respective Inceptdates were run, and there is virtually no difference between them, as the reader can visually verify from Figures 61 and 62. Further graphs at the 0.1% level of the Marchetti data simulation can be found in the appendix, as can the programs used to simulate the results from this chapter, and other chapters.

10.1 Effect of internal parameter changes.

A closer examination of this 'extended run' reveals that there is a 'natural frequency' of the peaks of the various sectors, after the initial inception period. This frequency measures around 150 years. Is this frequency invariant, or are there factors affecting it ? If there are factors, it is probably not an exogenous parameter. Rather, it is likely to be an internal parameter, such as FFESR or ECINFR. Testing these two internal parameters for any change in the frequency reveals that both parameters are determinants, but a change in FFESR has a more marked effect than in ECINFR. There may also be other parameters which influence the frequency.

An increase in the Depreciation of the sectors from 10% of their economic infrastructure to 20% and 25% had the effect of increasing the time constants of the market-share curves. In trying to simulate the Marchetti data with a Depreciation set at 10%, no amount of adjusting the Accessibility and Availability of each sector could alter the rise and fall times. But at 25%, the curves built up and decayed much more gradually, since their gradients were less. A best fit Depreciation of 22% was found to be most suitable for replicating the Marchetti data. This figure is therefore used throughout every simulation in this report, as is the 0.1% inception level (except where stated otherwise).

Decreasing the economic infrastructure of the energy sectors from $5\times E(v)$ to $3\times E(v)$ resulted in faster rise and fall times, conversely, increasing it from $5\times E(v)$ to $7\times E(v)$ slowed down the rise and fall times.

FIGURE 57- ABSOLUTE SUM OF ENERGY SECTOR NEW INFRASTRUCTURES 0.1%

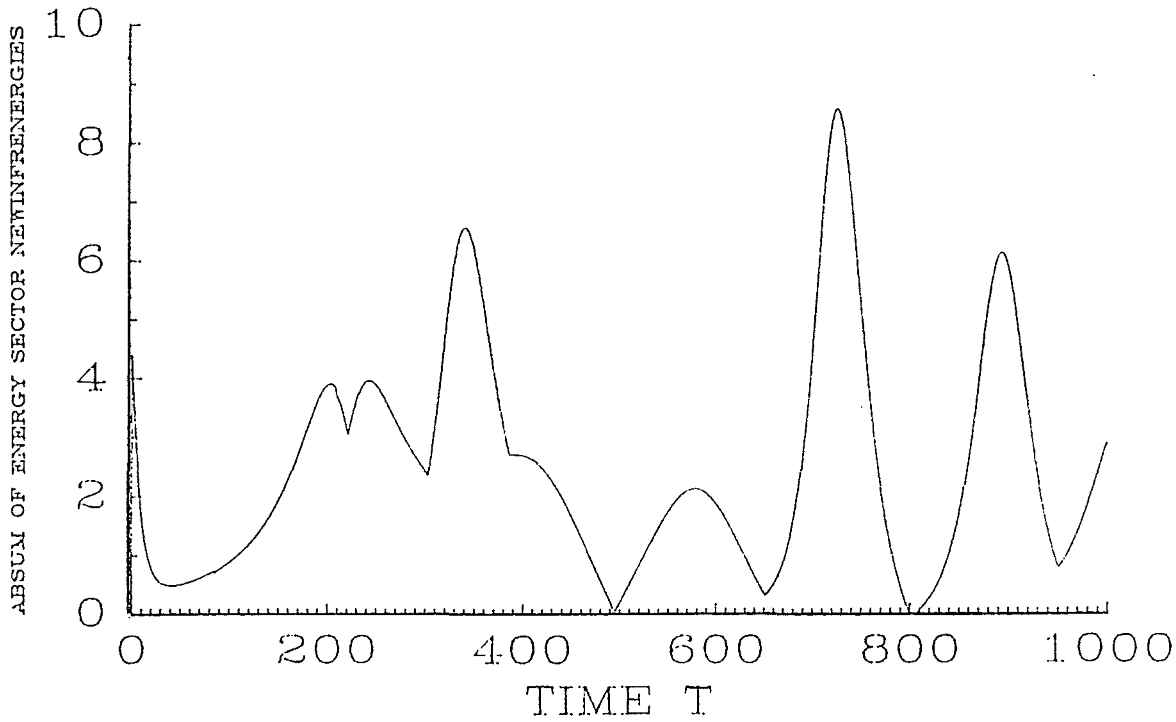


FIGURE 58- ABSOLUTE SUM OF ENERGY SECTOR NEW INFRASTRUCTURES 1%

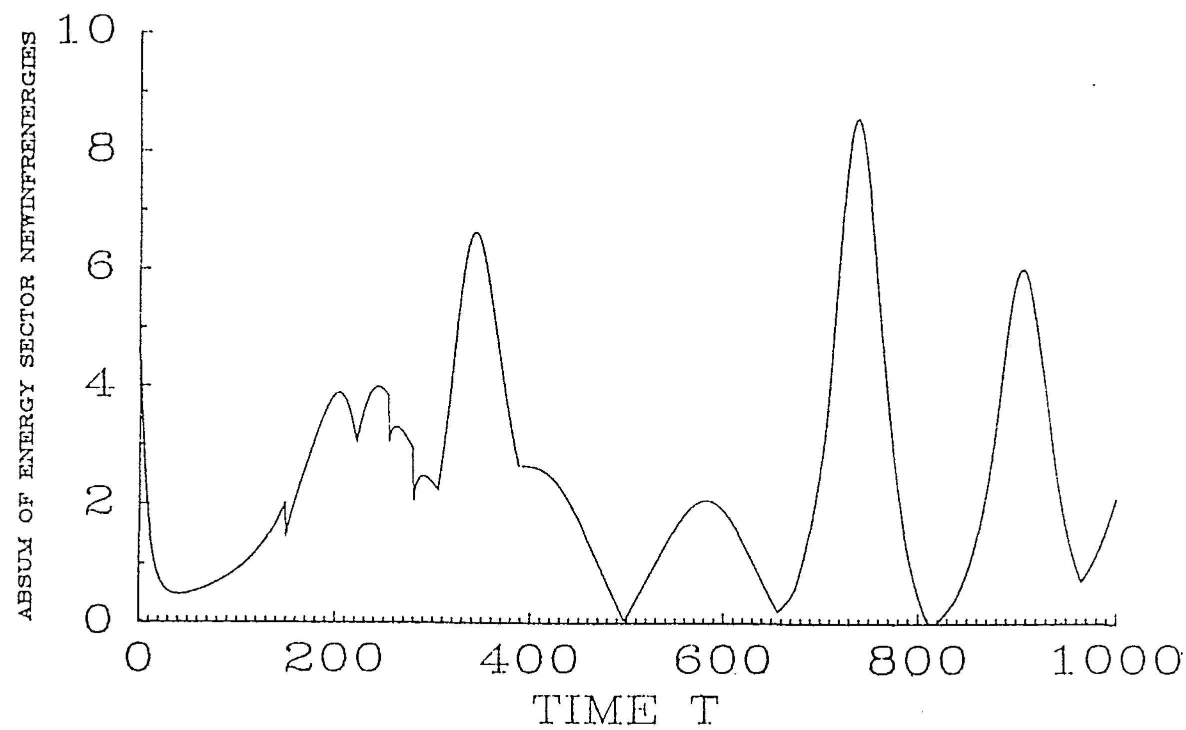


FIGURE 59- SUM OF ENERGY SECTOR NEW INFRASTRUCTURES 0.1%

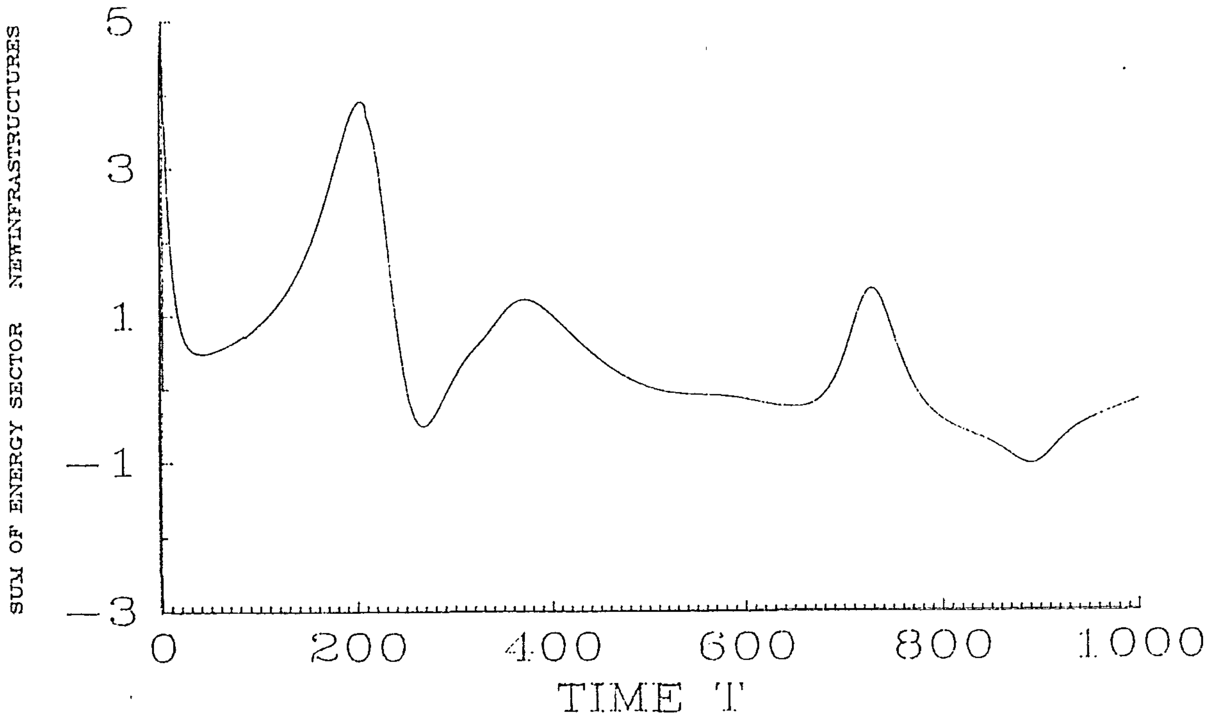


FIGURE 60- SUM OF ENERGY SECTOR NEW INFRASTRUCTURES 1%

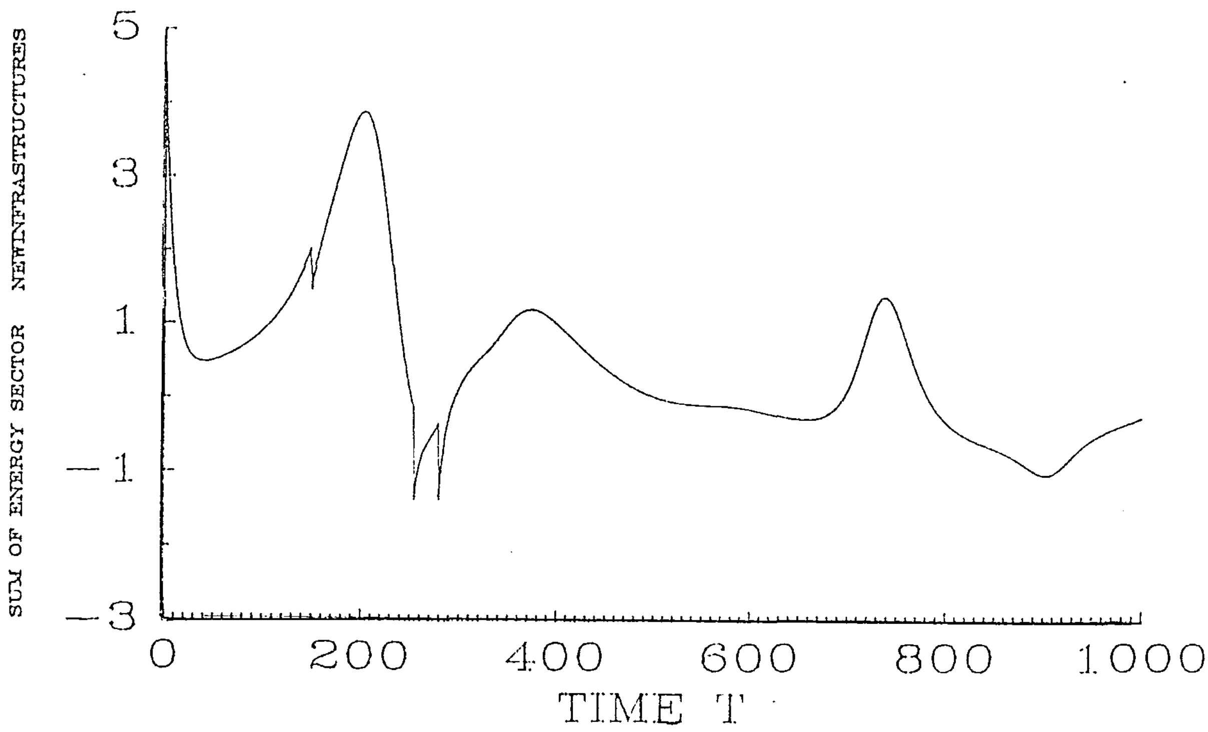


FIGURE 61 - EXTENDED RUN OF MARCHETTI DATA 1%

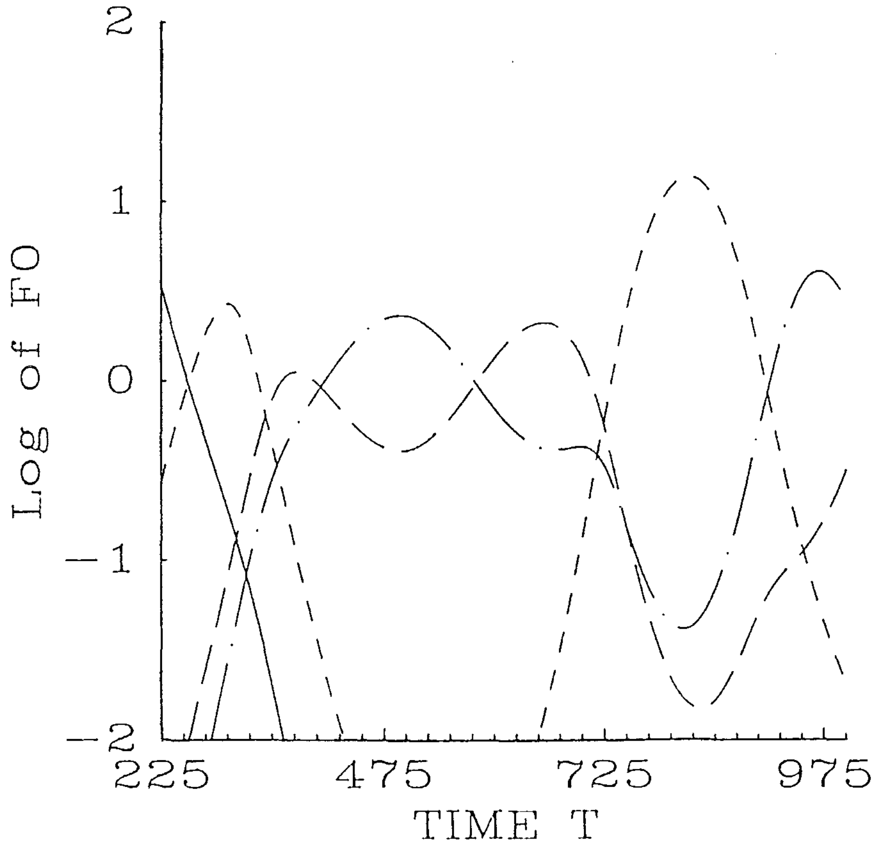
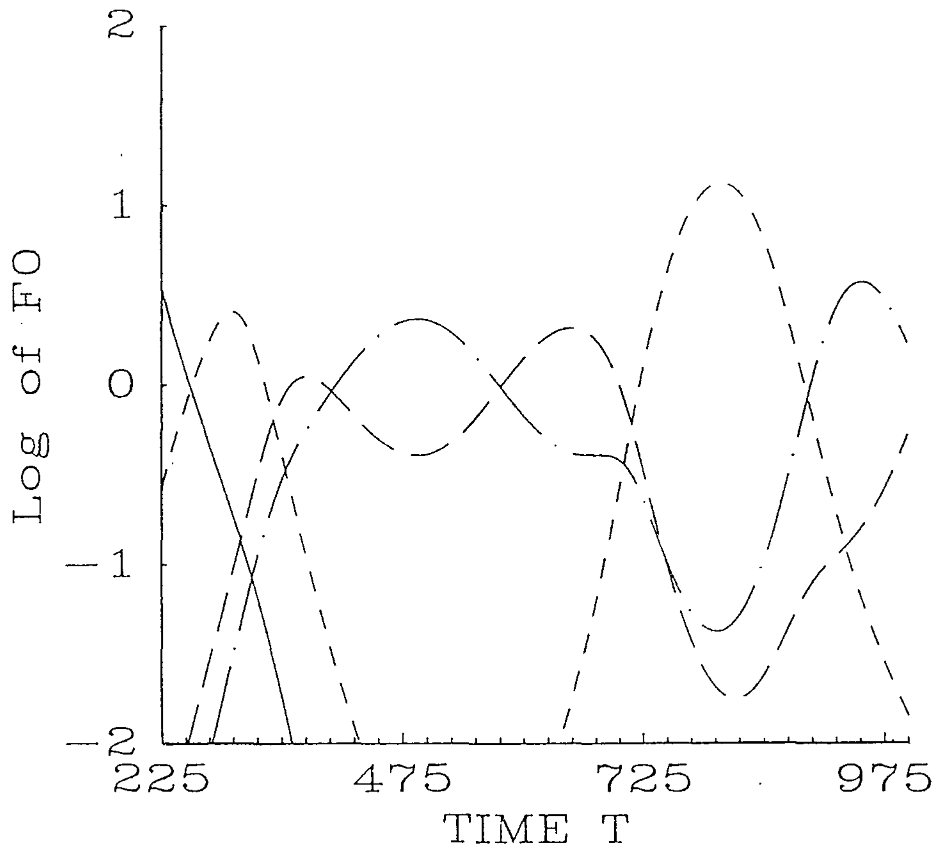


FIGURE 62 - EXTENDED RUN OF MARCHETTI DATA 0.1%



Chapter 11

Five sector simulation - nuclear.

Using the parameters for a 0.1% inception level with 4 stock sectors which correctly simulate the historical data of Marchetti, as discussed in Chapter 10, an attempt was made to fit the nuclear sector as the 5th stock sector, but changing the parameters of Accessibility, Availability and Inceptdate for the nuclear sector only. It was also intended to lower the Accessibility of the nuclear sector until it failed to penetrate (at the 1% level). The name assigned to the 5th sector is not important - it could be anything, it doesn't have to be nuclear. In fact, there is increasing evidence that nuclear power (fission anyway) is not an energy source, but a net energy sink, and therefore is not likely to be a future supplier of world energy. However, for the sake of a name, the 5th stock sector is called nuclear. (Nuclear would definitely not be a flow source because it needs radioactive elements from the earth - of which there is only a finite supply).

The results are mixed. Interestingly, there is no fixed break point for the nuclear sector. Figures 63 and 64 show that the higher its value of Accessibility, then the less it will be delayed in time before it penetrates - *but it does penetrate*. For example, with an Availability of 30,000 units, an Inceptdate of 313 years, and an Accessibility of 15, it reaches the 1% level in year 920 (Figure 63). When the Accessibility is raised to 18, it reaches the 1% level much earlier, at year 675 (Figure 64). So decreasing the Accessibility of the nuclear sector seems to lengthen the inception point (1%), and vice versa, increasing the Accessibility will shorten the time between Inceptdate and inceptpoint on the graph.

An important point to note here is that it was argued that each new sector will have an Accessibility greater than that of its immediately preceding sector if it is to penetrate the energy market. The work with the nuclear sector shows that this is not necessarily the case, because it *can* penetrate with an Accessibility *lower* than that of its immediately preceding sector (Gas, Accessibility = 24.0), albeit at a much later date. Figures 63 and 64

FIGURE 63 - MARKET SHARES

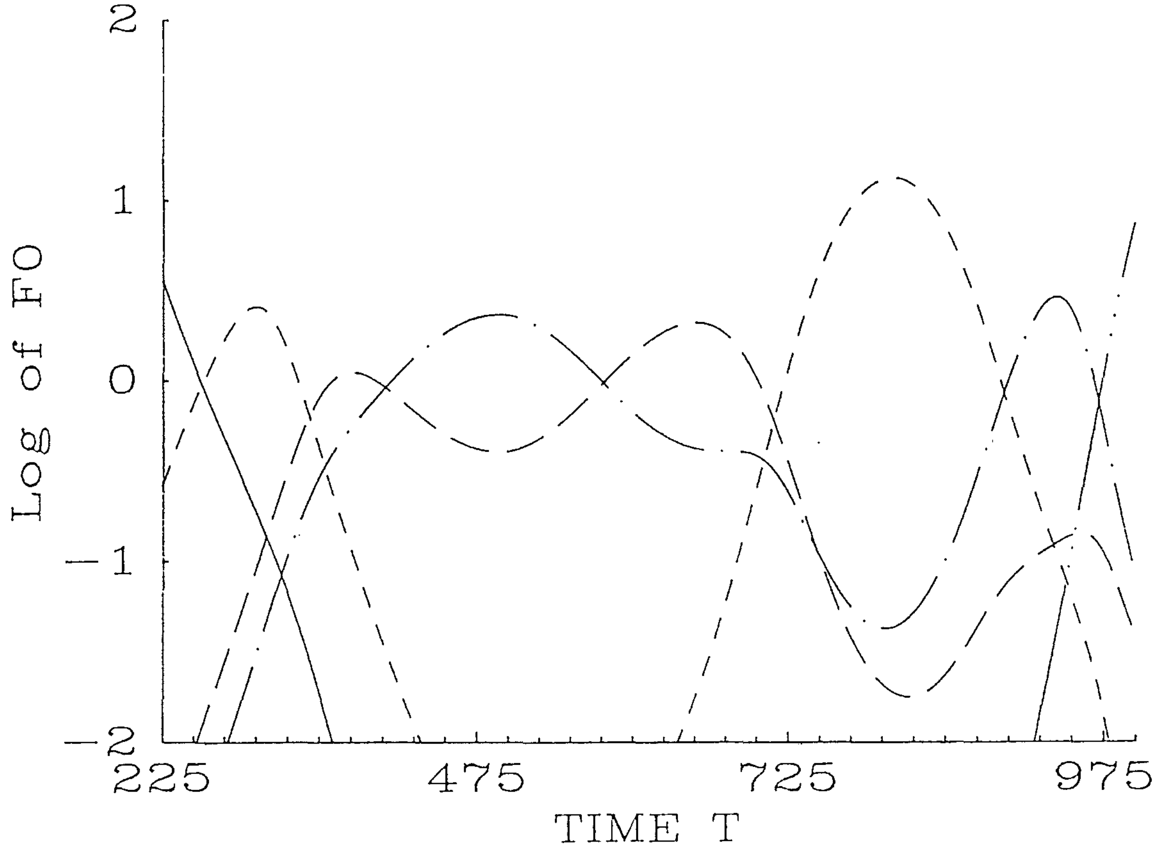
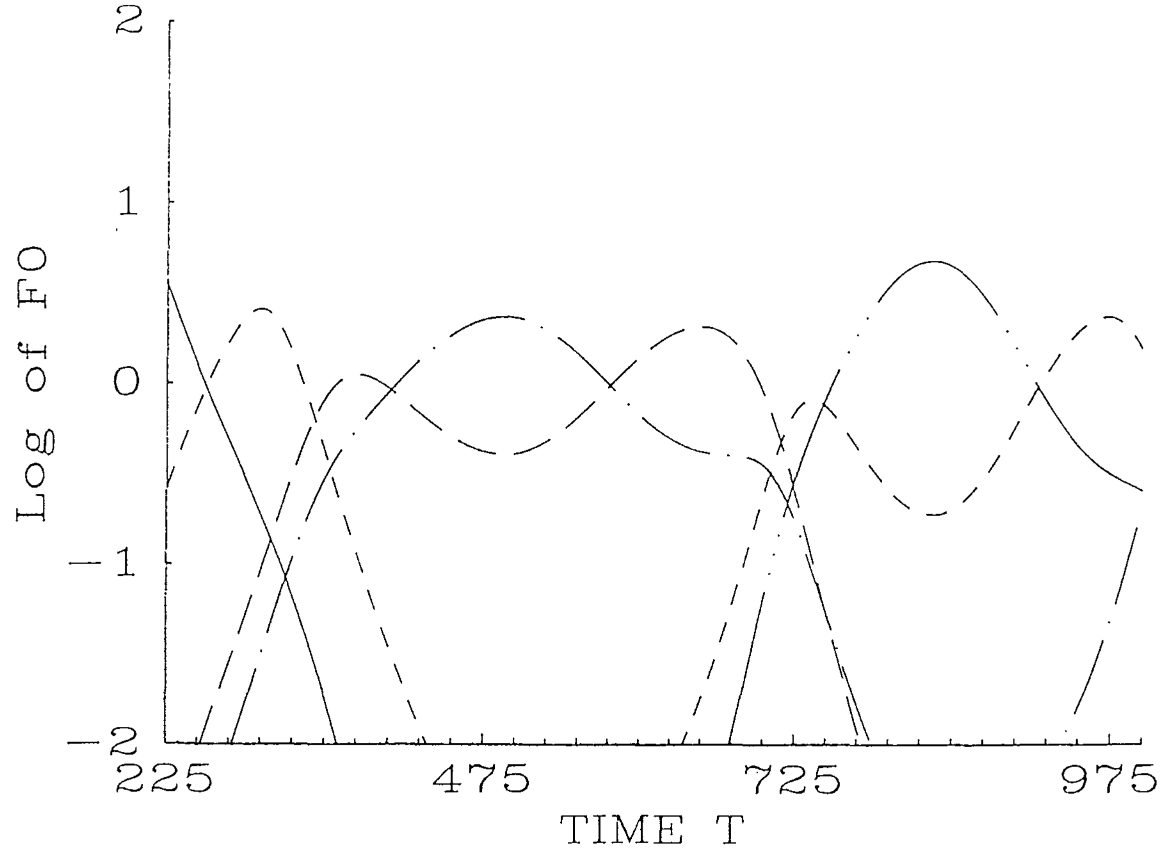


FIGURE 64 - MARKET SHARES



prove this.

Continued investigation suggests that a decrease in Availability of each of the other 4 sectors, relative to nuclear, will increase the market penetration of nuclear, but will not significantly alter its inception point. This applies if the Availability of nuclear is small relative to the other stock sectors. It also appears that a decrease in Availability of the sector immediately preceding nuclear (ie. Gas) causes an earlier inception point for the nuclear sector.

There is also an apparent anomaly between several plots of market shares. The nuclear sector is given an Accessibility of 24.0 in Figure 65, and 23.0 in Figure 66, yet it peaks at a higher level with the lower Accessibility (Figure 66). The Availabilities of the sectors are the same for both graphs. If the Availabilities are now changed, and the program rerun, the same effect occurs, but not to the same extent (Figures 67,68). The only difference to account for this reduced effect is the relative positioning of the Availability of Gas, going from 50,000 units in Figures 65,66 to 20,000 units in Figures 67,68 - from greater than that of nuclear (30,000) to less. It makes sense that the absolute levels of market share should alter with Availability, but it is puzzling why the nuclear sector should rise to a higher level with a lower Accessibility.

When the Accessibility of the nuclear sector is similar to that of Gas, and the Availabilities of the first 4 sectors are similar to each other, then the Availability of nuclear is swung relative to the other sectors. This results in a significant change in the level of market penetration for the nuclear sector (ie. the height reached on the graph), (Figures 69,70). A corresponding result is observed when the Accessibility of the nuclear sector is lower than that of Gas, (Figures 71,72). Table 11.1 is constructed from the empirical results of the work with the 5th sector. The Table shows the market share characteristic which is most affected by the change, or 'swing', of the Availability of Nuclear in two cases, and Gas in one case, both above and below the Availabilities of the other primary energies, with the Accessibility of Nuclear both similar, and low, compared to the Accessibility of Gas.

	Accessibility of Nuclear compared to Gas	
	Similar	Low
Availability of BCOG similar compared to nuclear, nuclear swings	height	height
Availability of BCOG high compared to nuclear, nuclear swings	height	no data
Availability of BCON similar compared to gas, gas swings	height	inceptpoint (1%)

Table 11.1: Market share characteristic most affected.

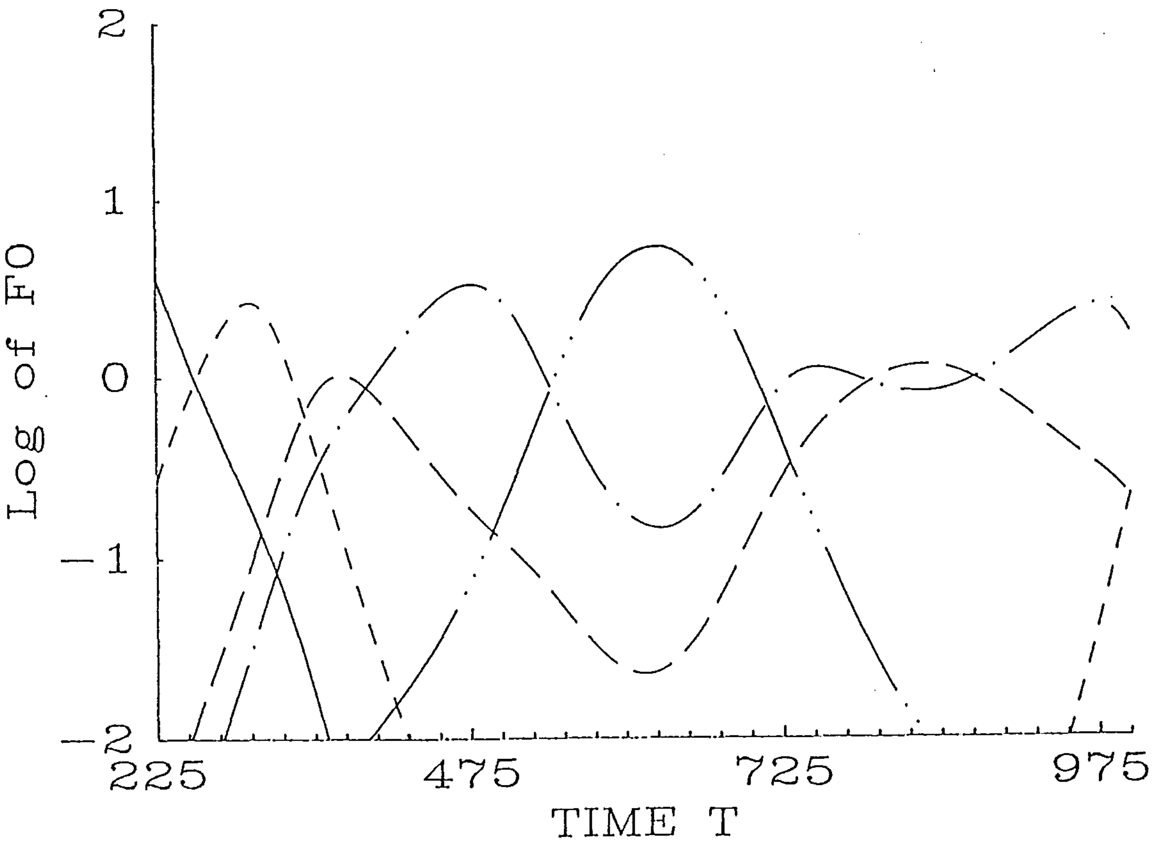


FIGURE 65 - MARKET SHARES

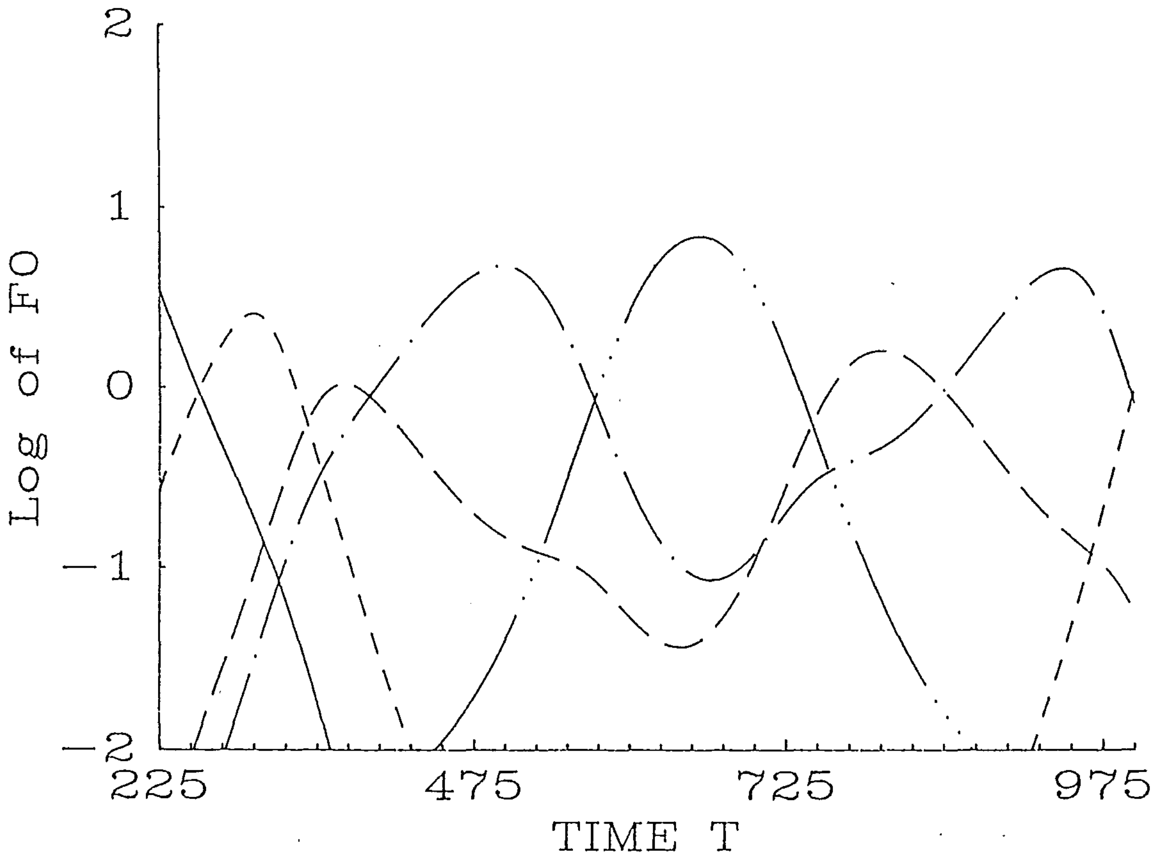


FIGURE 66 - MARKET SHARES

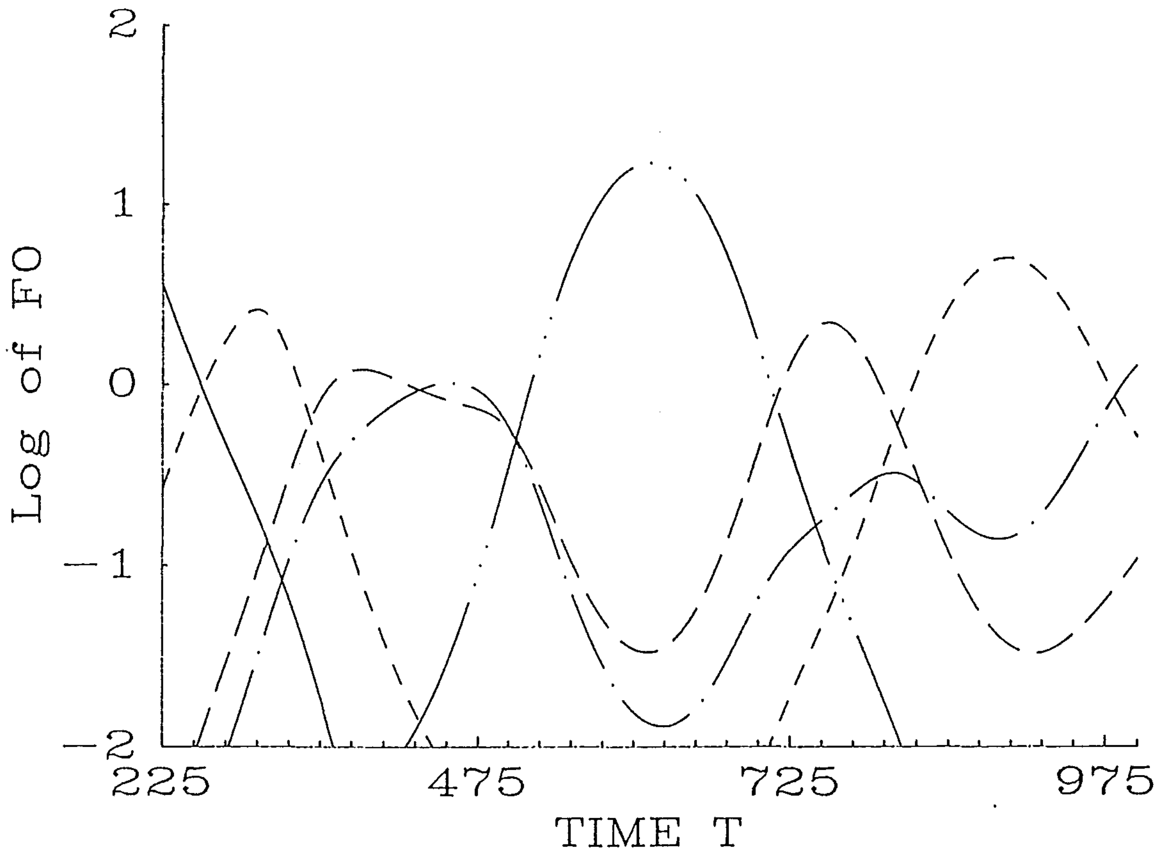


FIGURE 67 - MARKET SHARES

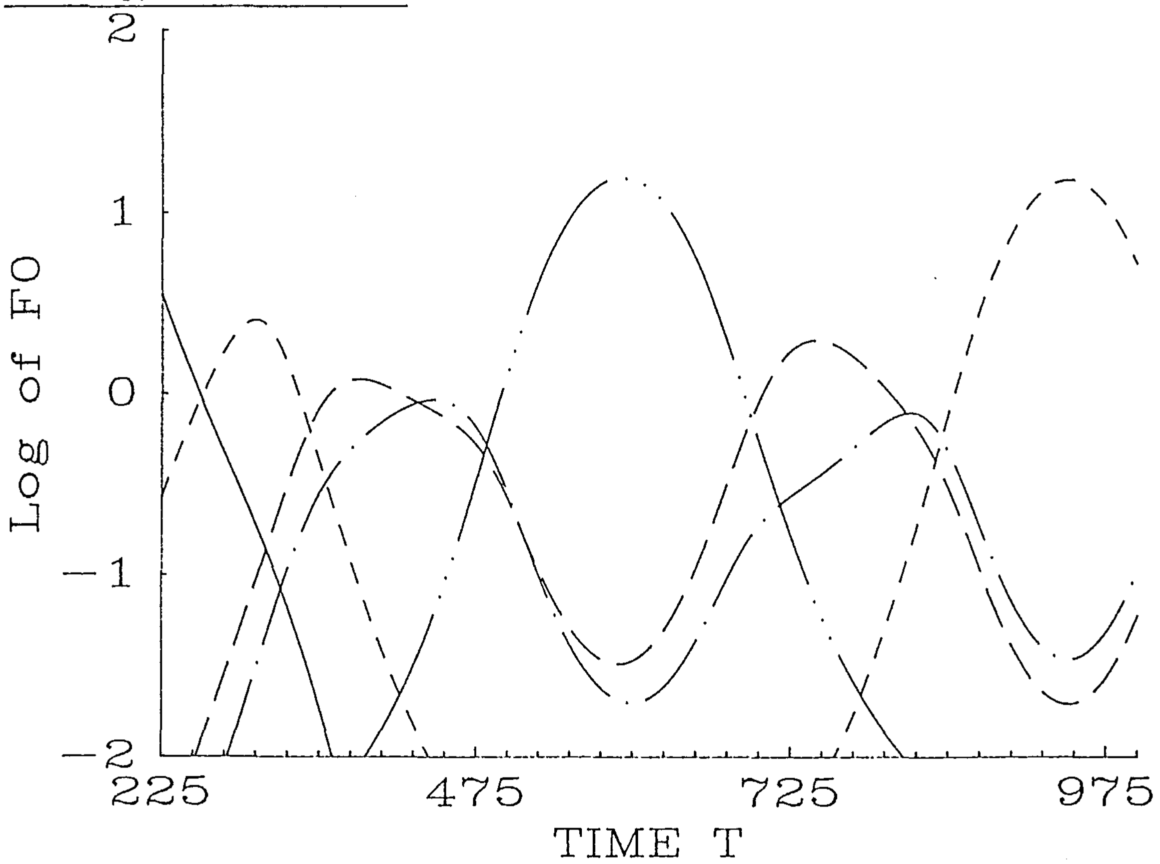


FIGURE 68 - MARKET SHARES

FIGURE 69 - MARKET SHARES

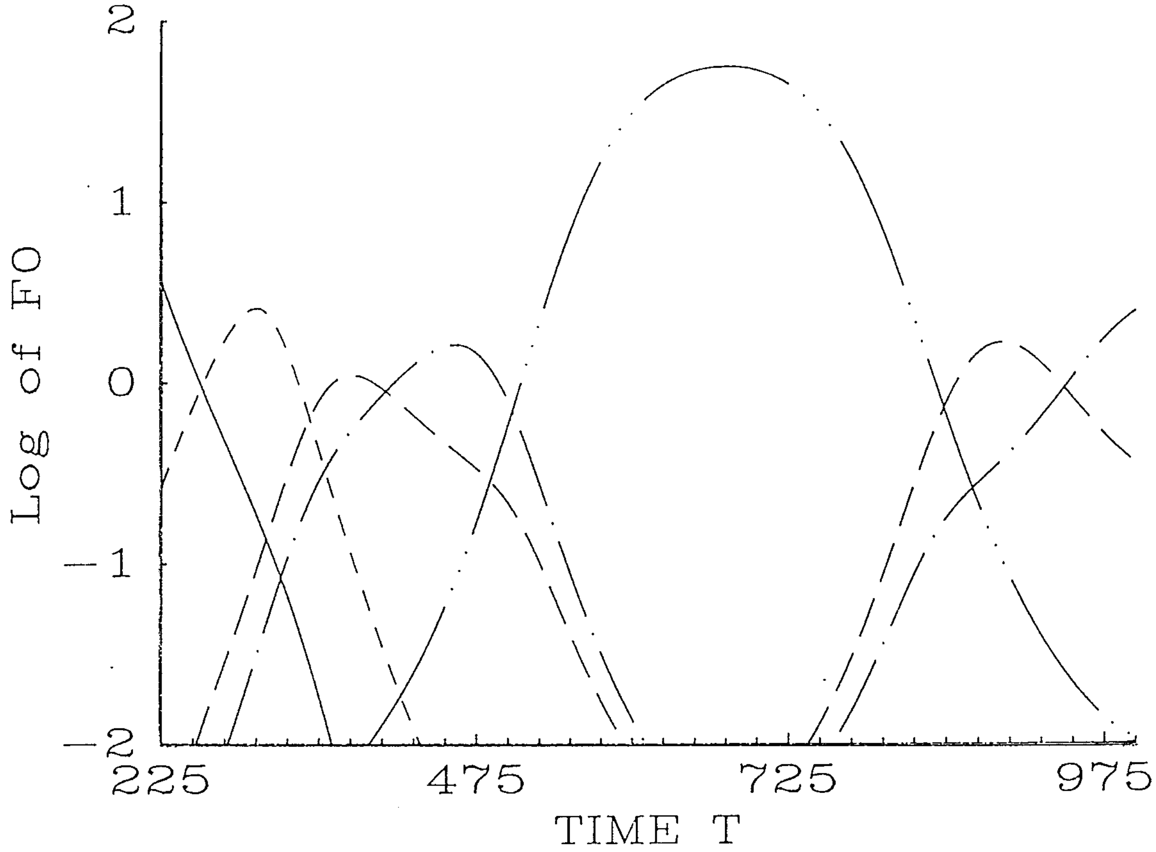


FIGURE 70 - MARKET SHARES

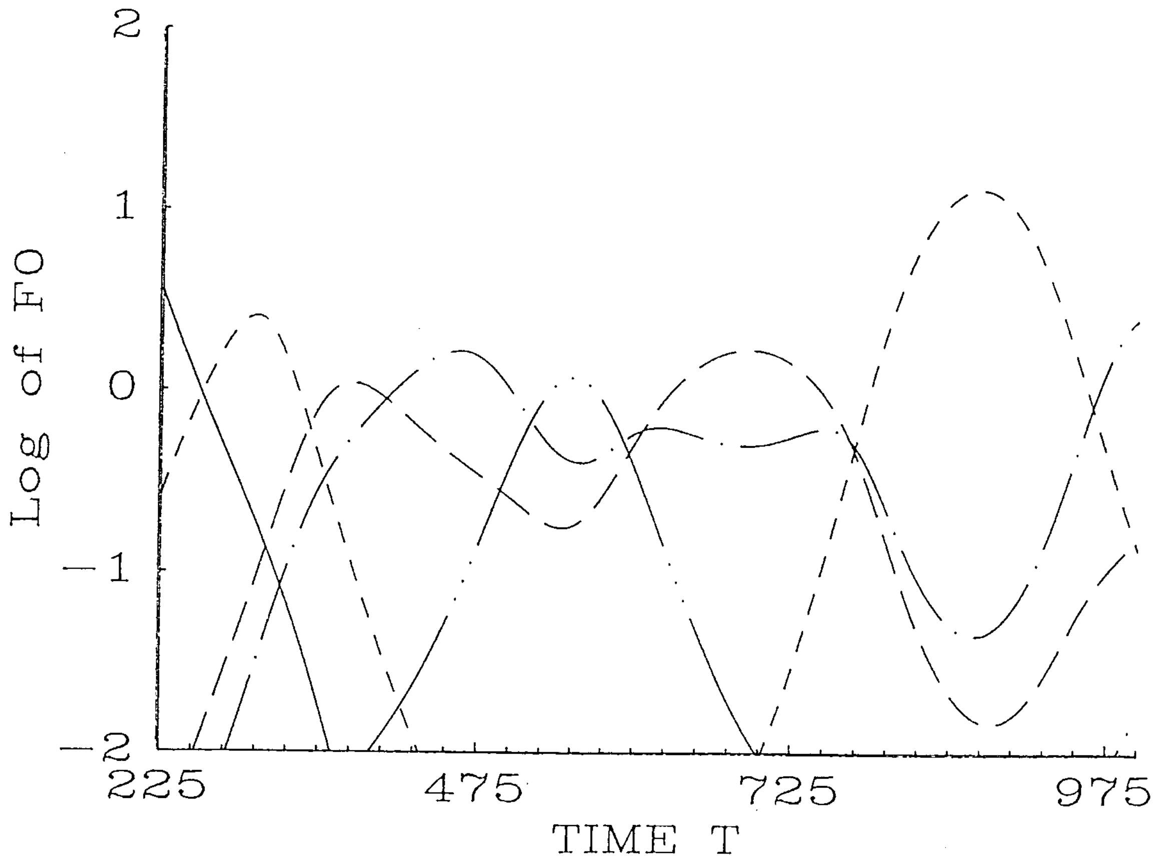


FIGURE 71 - MARKET SHARES

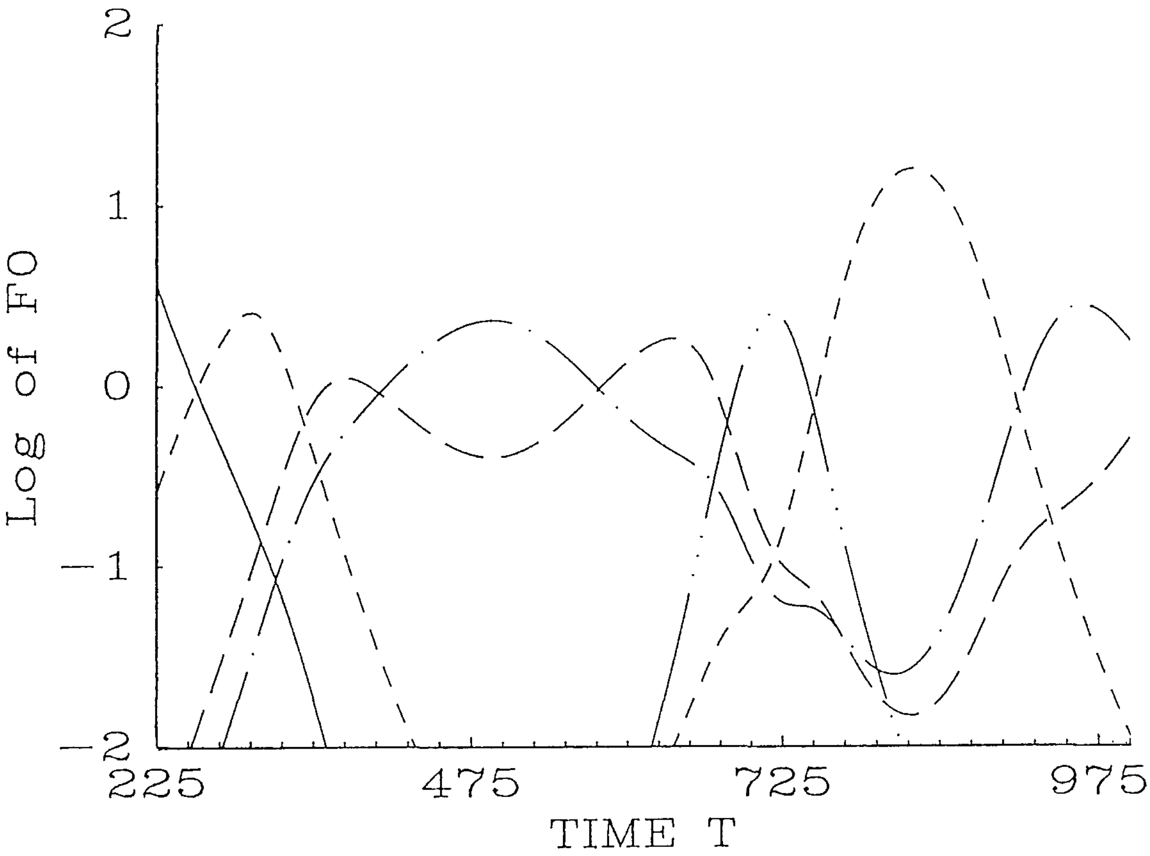
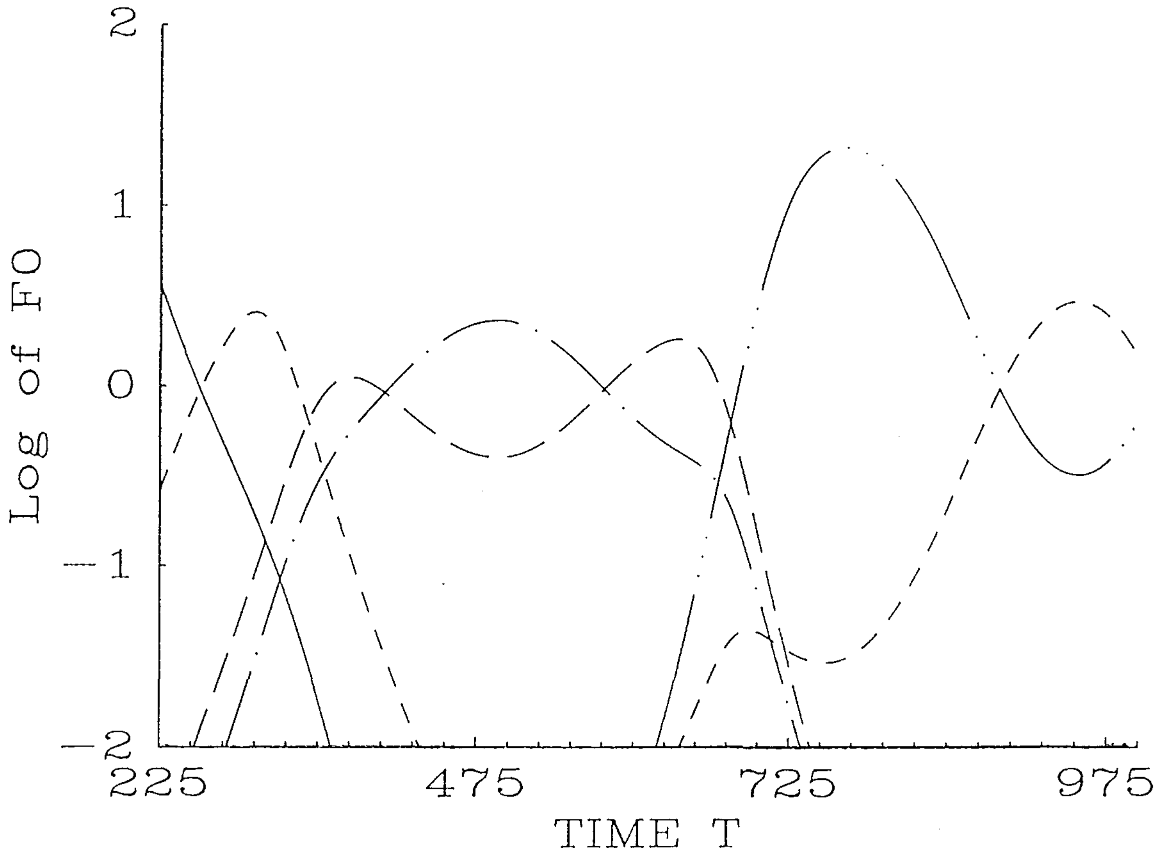


FIGURE 72 - MARKET SHARES



Chapter 12

A possible restructuring of the model.

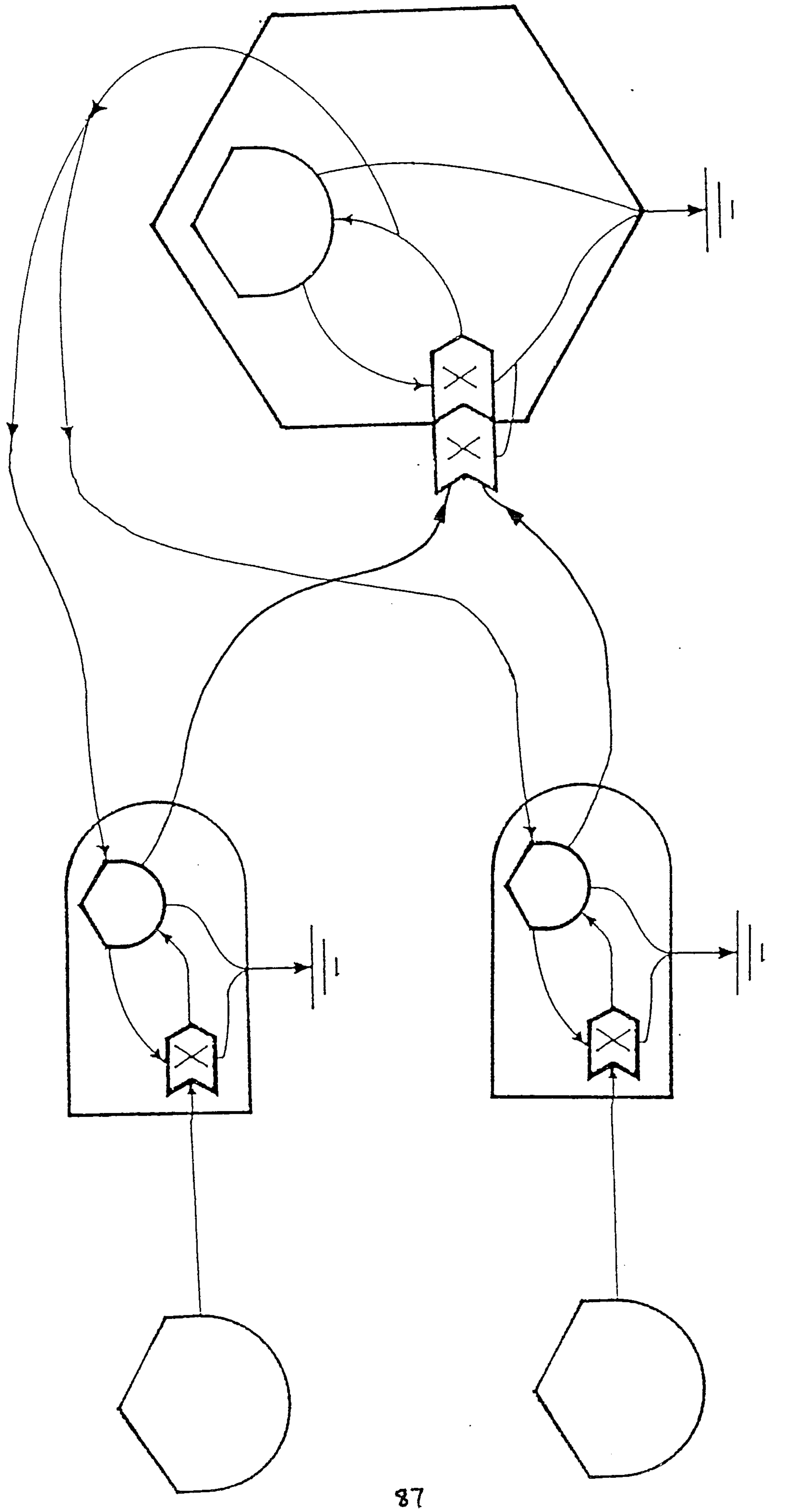
1. It may be desirable in the future to separate the energy component labelled 'DIRECT' into sub-components which are distinct from each other in a useful or helpful manner, for example, into certain types of vegetation. This may help in creating a better understanding of the embodied components inherent in the energy flow 'DIRECT'. The same applies to the FFEFS going into the refining industry. The central difference between FFEFS and DIRECT is that the former is generally managed, while the latter is generally unmanaged. Examples of a FFEFS are forestry, which is harvested for timber, agriculture and horticulture, where crops are managed for consumption, and hydro dams for power generation. Examples of the DIRECT component include unmanaged forestry, plant life, brush and vegetation, in fact, most natural things.

2. While the energy sector outputs are aggregated into NONSOLETOT, it may be preferable instead to have their outputs going directly to the workgate of the producer-consumer sector. The outputs would come from the energy sector workgates and go straight into their own infrastructures, and an output would come from the infrastructures to the consumer sector workgate, as in Figure 73.

Some of the model equations would necessarily change, but the overall patterns should be similar. This would make the storage tank, NONSOLETOT, redundant.

3. If the continued use of NONSOLETOT is desired, it may be necessary, for the sake of credibility, to rethink and remodel the role of NONSOLETOT in the equations for the consumer sector. The energy output is not directly governing the growth or decline of the consumer sector - rather, it is the value assigned to NONSOLETOT plus the energy sector outputs. Because the former is very large compared to the latter, then NONSOLETOT stimulates the growth patterns.

FIGURE 73 - A RESTRUCTURED MODEL. THE ENERGY SECTOR OUTPUTS ARE FED DIRECTLY TO THE WORKGATE. ONLY TWO ENERGY SECTORS ARE SHOWN.



Chapter 13

The metaphysical importance of Energy.

In this chapter, Jeremy Rifkin, the author of 'Entropy', states how energy, and its control, shape human society[7].

'Energy is the basis of human culture, just as it is the basis of life. Therefore, power in every society ultimately belongs to whosoever controls the exosomatic instruments that are used to transform, exchange and discard energy. Class division, exploitation, priviledge and poverty are all determined by how a society's energy flow line is set up. Those who control the exosomatic instruments control the energy flow line. They determine how the work in society will be divided up and how the economic rewards will be allocated among various groups and constituencies.'

Thus energy is fundamental to the form of a society. Rifkin then warns us of the dire consequences which face us if we do not change our ways, and proposes that in order to survive, we must respect our environment.

'Only by consciously choosing to respect the physical confines of this closed system we call the planet earth can we make the radical adjustment that is essential for our continuation as a species.'

'Our survival, and the survival of all other forms of life now depend on our willingness to make peace with nature and begin to live cooperatively with the rest of our ecosystem. If we do so, and allow the natural recycling process the time it needs to heal the wounds we have inflicted on the earth, then we, and all other forms of life can expect a long and healthy sojourn on this planet.'

'If we steadfastly refuse to make the change and continue in our colonizing ways, destroying everything in our path, we may find ourselves without a choice in the future. We will eventually reach that critical point where the matter-energy of the planet will be so depleted that even with a complete turnaround to the climactic mode, there will be too little low entropy terrestrial endowment left to allow the natural recycling process to restore a measure of ecological balance for the continuation of life.'

'The transition from a colonizing to a climactic mode of existence is the most profound change our species will ever have to make. That crossroads is now before us.'

In a similar vein, Fritjof Capra, the author of 'The Turning Point', warns of an approaching crisis, the enormity of which has never been experienced before[8].

'The current crisis, therefore, is not just a crisis of individuals, governments or social institutions; it is a transition of planetary dimensions. As individuals, as a society, as a civilization, and as a planetary ecosystem, we are reaching the turning point.'

He explains the need for change, specifically, to change from 'hard' to 'soft' technologies, from nonrenewable to renewable resources, from stock sectors to flow sources.

'The deepest roots of our current energy crisis lie in the patterns of wasteful production and consumption that have become characteristic of our society. To solve the crisis, we don't need more energy, which would only aggravate our problems, but profound changes in our values, attitudes and lifestyles.

... We need to shift our energy production from nonrenewable to renewable resources, and from hard to soft technologies, to achieve ecological balance. The energy policies of most industrialised countries reflect ... the 'hard energy path', in which energy is produced from nonrenewable resources such as coal, oil, gas and uranium.

... The only way out of the energy crisis is to follow a 'soft energy path', which would be environmentally benign and ecologically balanced.

... Since the role of fossil fuels as a bridge to the new, renewable energy resources is a vital element of the necessary transition, it will be crucial to start the transition process while we still have enough fossil fuels to guarantee a smooth passage.'

Chapter 14

Conclusions.

A dynamic systems model has been created to represent the interaction between refining industries, accessing primary energy or environmental stock reserves and a flow source, and the economic sector of society. The model is based solely on the flow, storage and dissipation of energy and as such has its roots in physical reality as governed by the Second Law of Thermodynamics.

It is concluded that the socio - economic sector does not have a predetermined level of energy demand over time, and equally, the energy sector yields to the socio - economic sector are not predetermined. Hence, energy and socio - economic growth are not solely a function of the energy sector flows, nor solely a function of socio - economic flows, but instead, each acts as an input to the other, resulting in complex, nonlinear dynamics.

The results of the computer simulation presented in the relevant chapters are important in their own right, but two sets of results have deep implications. These are the results from chapters 5 and 7, for 2 stock sectors, the first pertaining to the effect of an inception time differential in comparison with equal inception times, the second pertaining to the effect of widely varying Accessibilities. They are summarized as follows:

When two energy sectors of the same parameters simultaneously penetrate the market, they appear to cooperate and share the market equally. They act as a single sector. Yet, when they are separated in market penetration by a time differential, they behave aggressively, in competition with each other.

If a dynamic system of energy production and consumption, composed of two stock sectors, is to remain in a state of dynamic equilibrium, the Accessibilities of both stock sectors must be similar. If the Accessibilities are very dissimilar, there comes a time when there will be a massive increase in the energy output of one sector, akin to an impulse of energy, which signals the almost total depletion of both stock resources. Hence the system will become unbalanced, and highly disruptive.

The last point is the result from Chapter 8: a stock sector which has been formerly discarded, may be revisited at a later date. Implicit in this conclusion is the fact that the submission of a stock sector is not necessarily due to a total depletion of its resource, because the Availability of the stock sector must necessarily be greater than zero before it can be revived. However, if the Availability of the sector is exhausted, then it cannot be revisited.

Finally, as we look towards the future, it is apparent that our energy requirements cannot be sustained by nonrenewable stock resources. What is needed is an energy source that is renewable, is thermodynamically and economically efficient, and ecologically harmonious. Solar energy is a prime candidate. All the energy mankind has ever used (except nuclear power) represents a form of solar energy or stored solar energy. It is the energy, radiated from the sun and synthesised into wood, the fossil fuels of coal, oil and gas, which is consumed when we burn these fuels. The fossil fuels, however, are nonrenewable in terms of human lifespans. We must move away from these unrenewable resources, and towards renewable solar forms of energy.

As Fritjof Capra wrote, 'The soft energy path of renewable solar energy is in the best interests of the inhabitants of this planet, but a smooth passage to this new solar age is only possible if we place long term social returns before short term private gains. This will entail a profound transition of our society and culture.'

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Appendix A

A note on forecasting.

Prediction, planning, forecasting and scenarios. How valid, how reliable, how subjective and how scientific are they ? These are key questions to which there are no easy answers. Forecasters tend to concentrate on well - behaved situations that can be forecast with standard methodologies, and they tend to ignore the rapidly changing situation for which forecasts are most wanted[9]. Makridakis and Wheelwright[10] note 'Most econometric forecasts incorporate a substantial subjective element, reflecting the developer's own personal opinion about the future. Thus there is some question as to how much the quantitative model contributes to better forecasting and how much the judgemental input of the developer affects the results.'

'Application of quantitative approaches will continue to increase and supplement or replace many of the applications now handled through purely judgemental approaches.'

'Of course, it must be remembered that just as it is impossible to say which methodology is always best, it is impossible to conclude that quantitative methods are always better than subjective or judgementally based methods. Human forecasters can process much more information than most of the formalised quantitative methods, and such forecasters are more likely to have knowledge of specific near - term events that need to be reflected in current forecasts.'

One instance where judgemental forecasts are routinely generated is weather forecasting. The official forecasts predicted by the National Weather Service in the USA are subjective probability forecasts.

Murphy and Brown[11] have evaluated these subjective forecasts and found that for certain predicted categories of weather, they were more accurate than the available objective statistical techniques.

In this case the forecasters have a very large amount of information available including the output from objective statistical techniques. They also receive detailed feedback and have the opportunity to gain experience making forecasts under a wide range of meteorological conditions.

These circumstances may well be ideal for the relatively successful application of subjective, as opposed to objective, forecasting. They are certainly not the conditions available in most situations, when subjective judgement is elicited and utilised.

In discussing the possibility of combining judgemental and statistical forecasts, Makridakis et al argue that : 'Whereas purely judgemental approaches may suffer from a number of biases, formal quantitative forecasting methods suffer major difficulties in situations of significant environmental changes. Approaches that combine the best elements of both categories may well produce significantly improved results in comparison with those produced by using one or the other approaches alone... A logical conclusion is that forecasts should rely more heavily on the predictions provided by formal quantitative methods, as long as there are no major changes in the environment or organisation. When such changes do occur, judgemental inputs should be given more weight.'

Energy Analysis (EA) is largely objective and quantitative. But our model is somewhat more qualitative than quantitative. Does that make it more subjective, and therefore perhaps less valid ? Not in the opinion of the author. The parameters of Availability, Accessibility and Inceptdate can be changed at will, but these are parameters reflecting the hypothetical characteristics of energy sectors, ie. 'What if the Accessibility was raised by 50% ?'

F.A. Van Vught[12] raises the question of forecasting being an art or a science. He notes that most serious forecasters around the world would not hesitate to call it a science. Yet, as a scientific discipline, '...forecasting is not based on a solid foundation. Especially from the perspective of the philosophy of science, questions about the scientific character of forecasting can be raised, which can embarrass the rapidly developing discipline.'

He presents 'pitfalls of forecasting' from the perspective of the philosophy of science. They concern mistakes in reasoning about the future, and are summarised as follows:

A.1 The pitfall of false continuity.

Our knowledge and experience concern the past, yet we have to make decisions for the future. Will the future be like the past ? The inductive argument says that based on an observed regularity in a limited number of cases, it is possible to formulate a general statement concerning the regularity in all similar cases. Yet, it is pointed out that the inductive argument cannot be logically justified.

A.2 The pitfall of ignoring theories.

Science is a matter of designing and testing theories with the observations of reality. Because of these designed and tested theories, we can formulate certain predictions about the future, given a set of empirical phenomena.

Theories contain general statements about reality that have not yet been refuted. When we want to make practical predictions, it is wise to rely upon these sets of argued statements. Theories provide us with a base to formulate predictions. However, in the literature on forecasting, hardly any attention is paid to the design of theories.

A.3 The pitfall of corroboration.

Even when theories are available, prudence is in order. A theory that has often been tested and still has not been refuted has a certain degree of corroboration. Many think that predictions based on theories that are tested often and severely (and still have not been refuted) are more probable than predictions based on less corroborated theories. Yet, there is no reason to believe (from Hume's analysis) that a theory with a high degree of corroboration will survive future tests better than a theory with a low degree of corroboration.

Predictions deduced from a theory do not become more probable when the number of tests is higher, and the nature of the tests is more severe.

A.4 The pitfall of intuition.

In subjective forecasting techniques generally, no use is made of theories. The idea of causality is of no account. Forecasts are not produced by deducing them from scientific theories, but by using information from the past and present on the variables of interest.

The fundamentals of many subjective forecasting techniques are sought in the use of expert opinions. However, the specialised experts have no scientific base for claiming their subjective forecasts to be rational.

A.5 The pitfall of scientific determinism.

Scientific determinism asserts that, when true universal theories are available and when all the initial conditions can be formulated from the past and present, then the future can be rationally calculated. In other words, any state of any system at any future time can be predicted when we have at our disposal the theories and initial conditions. But this is a totally unrealistic expectation, for we can never formulate all the relevant laws or list all the initial conditions.

Appendix B

Derivation of Model Equations - DIRECT, FFEFS.

There are 3 basic equations which are manipulated to form the desired equations for DIRECT and FFEFS:

(1A). FFEFS = k(1) $\times$ ECINFR(1) $\times$ R(1)

Equation (1A) states that FFEFS is multiplicatively dependent on a constant, k(1), on the infrastructure of the flow source refining industry, ECINFR(1), and on R(1). It is dependent on ECINFR(1) because the size of the infrastructure directly affects the ability of the refining industry to process the energy flow. However, it is slightly more difficult to see the dependence on R(1). If R(1) is treated as a storage tank, similar to the stock reserve storages, but with a constant flow source input of EFS, and outputs of DIRECT and FFEFS, then one can draw the parallel to the equation for FFEFS from FFESR (Equation 3(b) in the text). Hence FFEFS is directly proportional to the untapped quantity R(1).

(2A). DIRECT = kk $\times$ NONSOLETOT $\times$ ECINFRC $\times$ R(1)

Equation (2A) is similar to (1A), but with the further component of NONSOLETOT. This is included because it is argued that an increase in the energy sector outputs to the socio-economic sector, and therefore an increase in NONSOLETOT, results in growth and expansion of the latter sector. Consequently, there will be an increase in the human population, increasing the usage of DIRECT - that is, of unmanaged biological matter, used for example as fuel, or timber.

(3A). EFS = FFEFS + DIRECT + R(1)

Equation (3A) is a zero sum gain equation, where the sum of FFEFS, DIRECT and R(1) equal the total solar flux emanating from the flow source.

Manipulation of (3A) produces (4A).

(4A). R(1) = EFS - FFEFS - DIRECT

Substitution in the expressions for FFEFS and DIRECT from (1A) and (2A) produces (5A).

(5A). R(1) = EFS/(1 + (k(1) $\times$ ECINFR(1)) + (kk $\times$ ECINFRC $\times$ NONSOLETOT))

Substituting this expression for R(1) in equation (2A) produces (6A).

(6A). FFEFS = k(1) $\times$ ECINFR(1) $\times$ EFS /(1 + (kk $\times$ NONSOLETOT $\times$ ECINFRC) + (k(1) $\times$ ECINFR(1)))

Substituting (5A) for R(1) in (2A) produces (7A).

(7A). DIRECT = kk $\times$ NONSOLETOT $\times$ ECINFRC $\times$ EFS /(1 + (kk $\times$ NONSOLETOT $\times$ ECINFRC) + (k(1) $\times$ ECINFR(1)))

These latter two equations are given as model equations.

Appendix C

Parameter list for Figures.

The following data are the parameters for the figures used throughout this report.

		Availability	Inceptdate	Accessibility
Figure 4				
	C	8000	0	5

Figure 5

Same parameters as Figure 4.

Figure 6

Same parameters as figure 4.

Figure 7

Same parameters as figure 4.

Figure 8

Same parameters as figure 4.

Figure 9

Same parameters as figure 4.

Figure 10

Same parameters as figure 4.

Figure 11

Same parameters as figure 4.

Figure 12

C	8000	0	5
0	8000	0	5

Figure 13

Same parameters as figure 12.

Figure 14

Same parameters as figure 12.

Figure 15

C	8000	0	5
0	8000	1	5

Figure 16

Same parameters as Figure 15.

Figure 17

Same parameters as Figure 15.

Figure 18

Same parameters as Figure 15.

Figure 19

Same parameters as Figure 15.

Figure 20

Same parameters as Figure 15.

Figure 21

Same parameters as Figure 15.

Figure 22

C	8000	224	25
O	8000	226	25

Figure 23

C	4000	224	25
O	8000	226	25

Figure 24

C	8000	224	25
O	4000	226	25

Figure 25

C	8000	224	20
O	8000	226	25

Figure 26

C	8000	224	15
O	8000	226	25

Figure 27

C	8000	224	10
O	8000	226	25

Figure 28

C	8000	224	25
O	8000	526	25

Figure 29

C	8000	224	5
O	8000	526	5

Figure 30

C	8000	224	5
O	8000	326	5

Figure 31

C	8000	224	5
O	8000	226	5

Figure 32

C	8000	224	10
O	8000	226	10

Figure 33

Same parameters as Figure 32.

Figure 34

Same parameters as Figure 32.

Figure 35

C	8000	224	5
O	8000	226	10

Figure 36

Same parameters as Figure 35.

Figure 37

Same parameters as Figure 35.

Figure 38

C	8000	224	10
O	8000	226	5

Figure 39

Same parameters as Figure 38.

Figure 40

Same parameters as Figure 38.

Figure 41

B	9898.9	224	10
C	20,000	225	25

Figure 42

B	9898.9	224	10
C	10,000	225	25

Figure 43

B	9898.9	224	10
C	20,000	225	30

Figure 44

B	9898.9	224	10
C	20,000	230	20

Figure 45

B	9898.9	224	10
C	1000	225	25

Figure 46

Same parameters as Figure 45.

Figure 47

B	9898.9	224	10
C	2000	225	25
O	2000	226	25

Figure 48

B	9898.9	224	10
C	2000	225	25
O	2000	250	25

Figure 49

B	9898.9	224	10
C	2000	225	25
O	2000	230	25

Figure 50

B	9898.9	224	10
C	2000	225	25
O	1000	226	25

Figure 51

B	9898.9	224	10
C	1000	225	25
O	2000	226	25

Figure 52

B	9898.9	224	10
C	5000	225	15
O	5000	226	25

Figure 53

Same parameters as Figure 52

Figure 54

Same parameters as Figure 52

Figure 55

No parameters.

Figure 56 (0.1%)

B	9898.9	0	10
C	26,000	85	21.5
O	28,000	210	23.5
G	30,000	233	24.0

Figure 57

Same parameters as Figure 56.

Figure 58 (1%)

B	9898.9	0	10
C	26,000	150	21.5
O	28,000	255	23.5
G	30,000	280	24.0

Figure 59 (0.1%)

Same parameters as Figure 56.

Figure 60 (1%)

Same parameters as Figure 58.

Figure 61

Same parameters as Figure 58.

Figure 62

Same parameters as Figure 56.

Figure 63

B	9898.9	0	10
C	26,000	85	21.5
O	28,000	210	23.5
G	30,000	233	24.0
N	30,000	313	15.0

Figure 64

B	9898.9	0	10
C	26,000	85	21.5
O	28,000	210	23.5
G	30,000	233	24.0
N	30,000	313	18.0

Figure 65

B	9898.9	0	10
C	26,000	85	21.5
O	28,000	210	23.5
G	50,000	233	24.0
N	30,000	313	24.0

Figure 66

B	9898.9	0	10
C	26,000	85	21.5
O	28,000	210	23.5
G	50,000	233	24.0
N	30,000	313	23.0

Figure 67

B	9898.9	0	10
C	26,000	85	21.5
O	28,000	210	23.5
G	20,000	233	24.0
N	30,000	313	23.0

Figure 68

B	9898.9	0	10
C	26,000	85	21.5
O	28,000	210	23.5
G	20,000	233	24.0
N	30,000	313	24.0

Figure 69

B	9898.9	0	10
C	26,000	85	21.5
O	28,000	210	23.5
G	30,000	233	24.0
N	60,000	313	24.0

Figure 70

B	9898.9	0	10
C	26,000	85	21.5
O	28,000	210	23.5
G	30,000	233	24.0
N	10,000	313	24.0

Figure 71

B	9898.9	0	10
C	26,000	85	21.5
O	28,000	210	23.5
G	30,000	233	24.0
N	10,000	313	19.0

Figure 72

B	9898.9	0	10
C	26,000	85	21.5
O	28,000	210	23.5
G	30,000	233	24.0
N	60,000	313	19.0

Figure 73

No parameters.

Figure 74

Same parameters as Figure 56.

Figure 75

Same parameters as Figure 56.

Figure 76

Same parameters as Figure 56.

Figure 77

Same parameters as Figure 56.

Figure 78

Same parameters as Figure 56.

Figure 79

Same parameters as Figure 56.

Figure 80

Same parameters as Figure 56.

Figure 81

Same parameters as Figure 56.

Figure 82

Same parameters as Figure 56.

Figure 83

Same parameters as Figure 56.

Figure 84

Same parameters as Figure 56.

Figure 85

Same parameters as Figure 56.

Figure 86

Same parameters as Figure 56.

Figure 87

Same parameters as Figure 56.

Figure 88

Same parameters as Figure 56.

Appendix D

Marchetti simulation data (0.1%) - further graphs.

FIGURE 74 - YIELDS FROM THE ENERGY REFINING INDUSTRIES

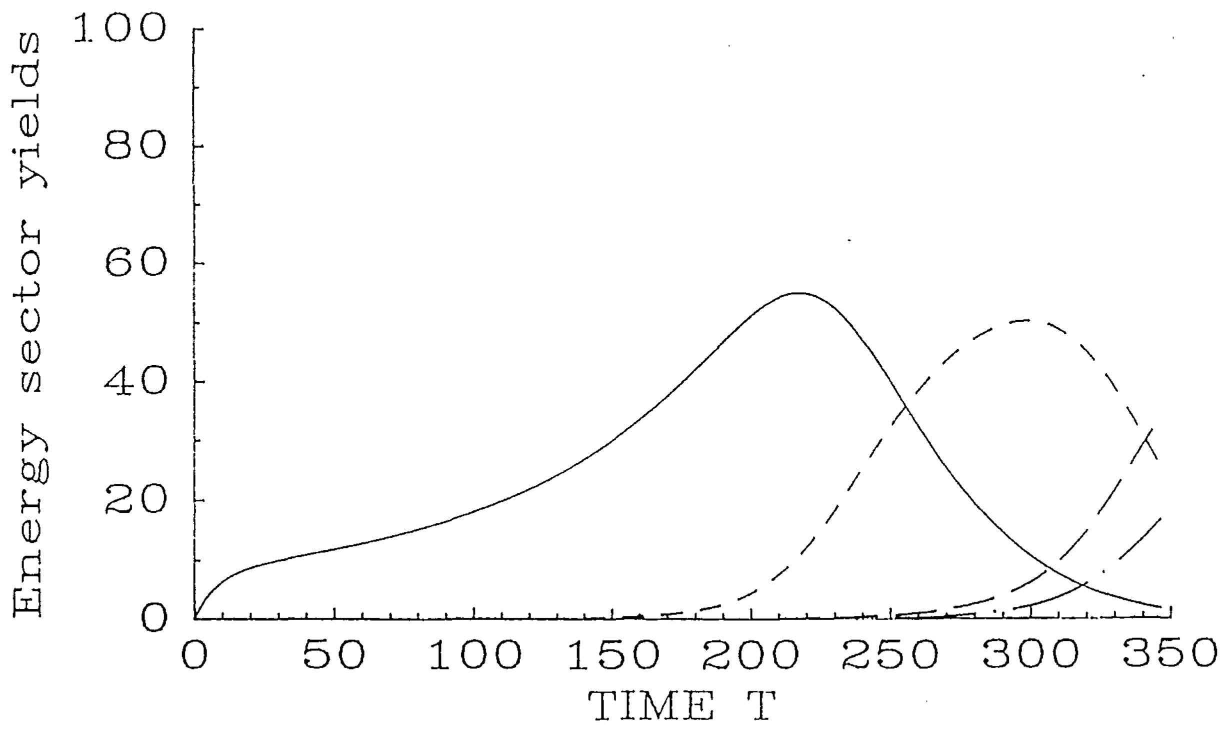


FIGURE 75 - ENERGY FLOWS FROM SOURCE TO REFINING INDUSTRY

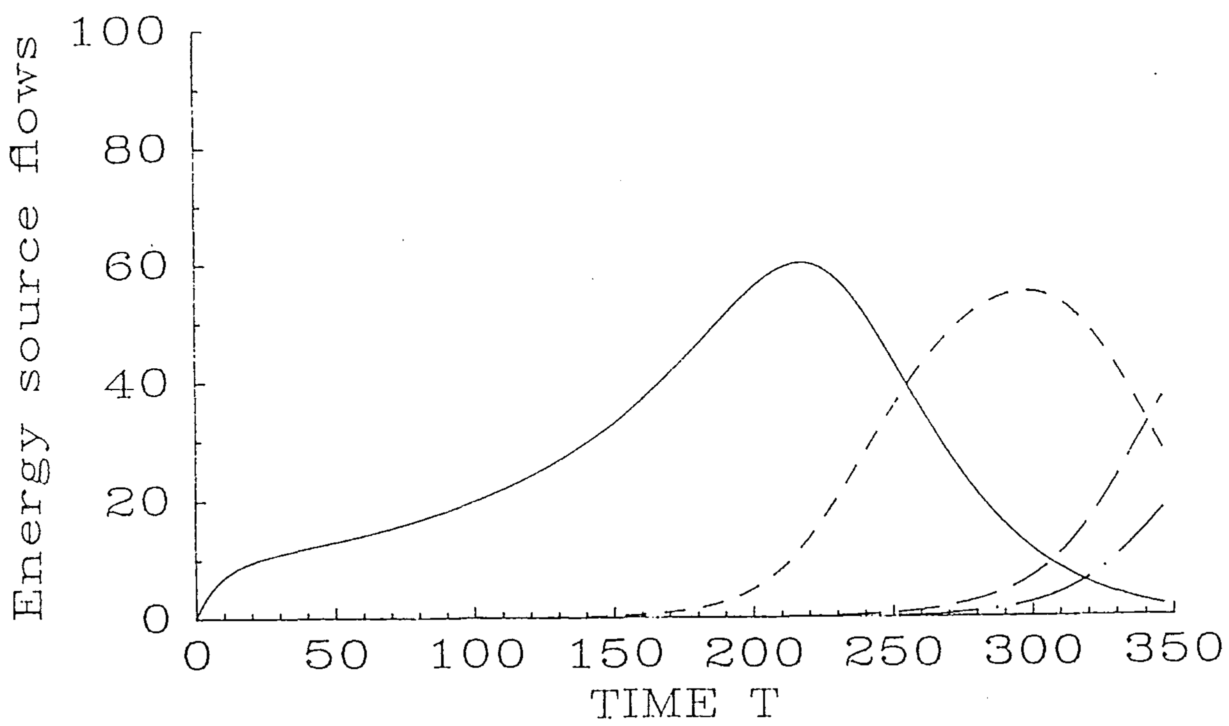


FIGURE 76 - SUM OF THE ENERGY SUPPLY SECTOR YIELDS

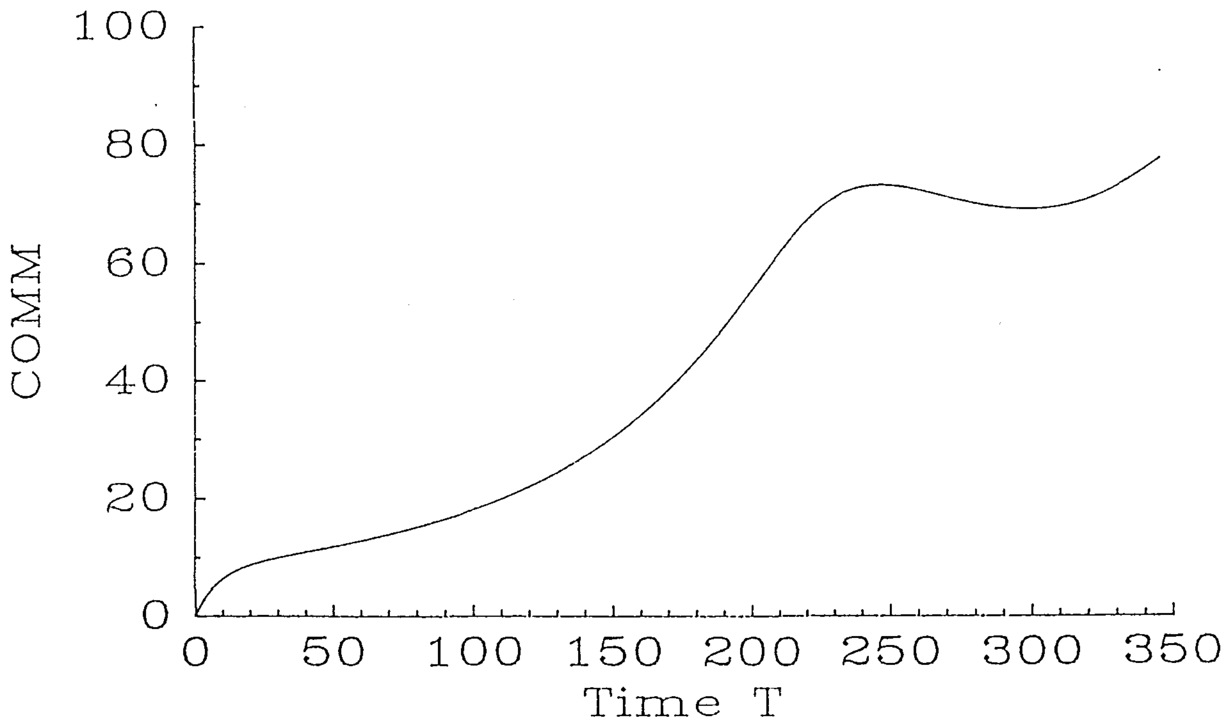


FIGURE 77 - ENERGY REFINING INDUSTRY INFRASTRUCTURES

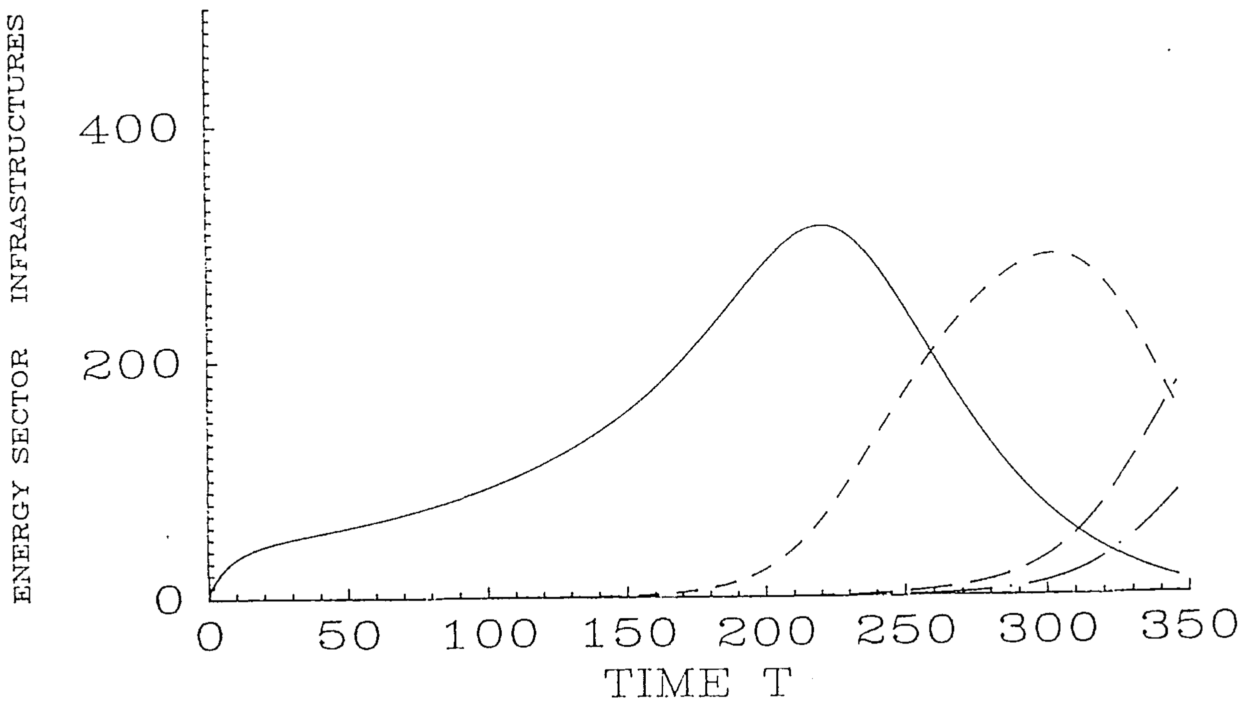


FIGURE 78 - SUM OF THE ENERGY SECTOR INFRASTRUCTURES

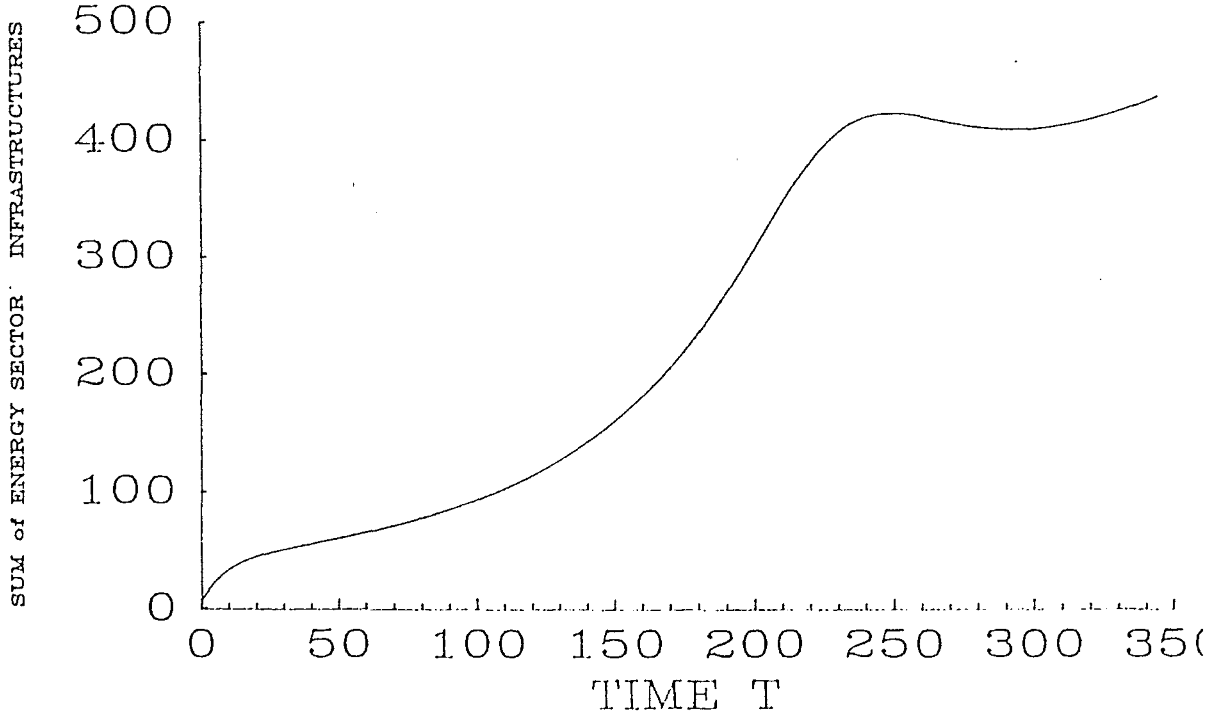


FIGURE 79 - NEW INFRASTRUCTURE ADDED TO THE ENERGY REFINING INDUSTRY

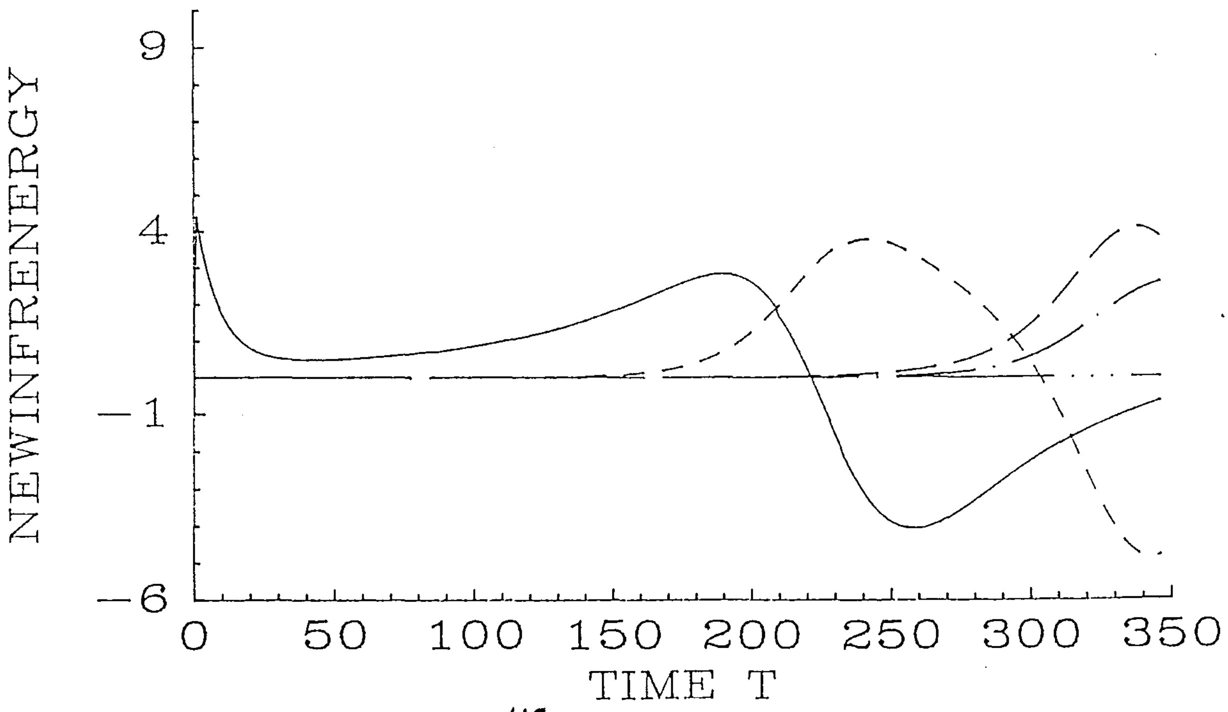


FIGURE 80 - SUM OF ENERGY SECTOR NEW INFRASTRUCTURES 0.1%

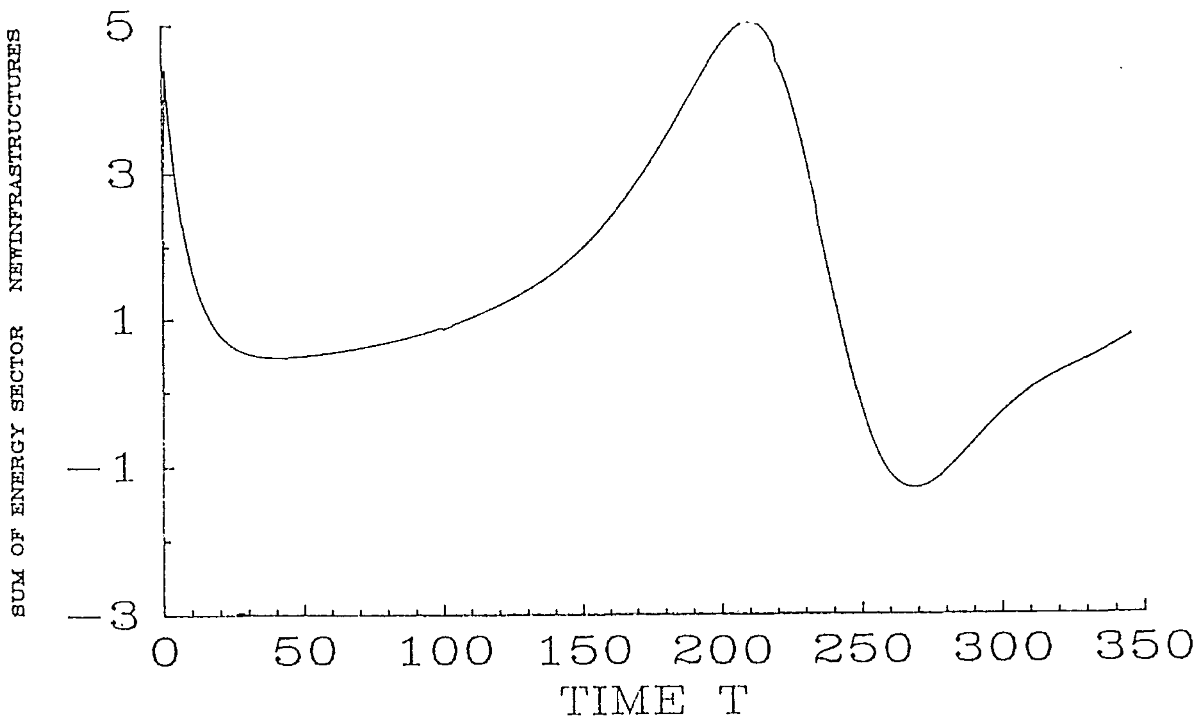


FIGURE 81 - ABSOLUTE SUM OF ENERGY SECTOR NEW INFRASTRUCTURES 0.1%

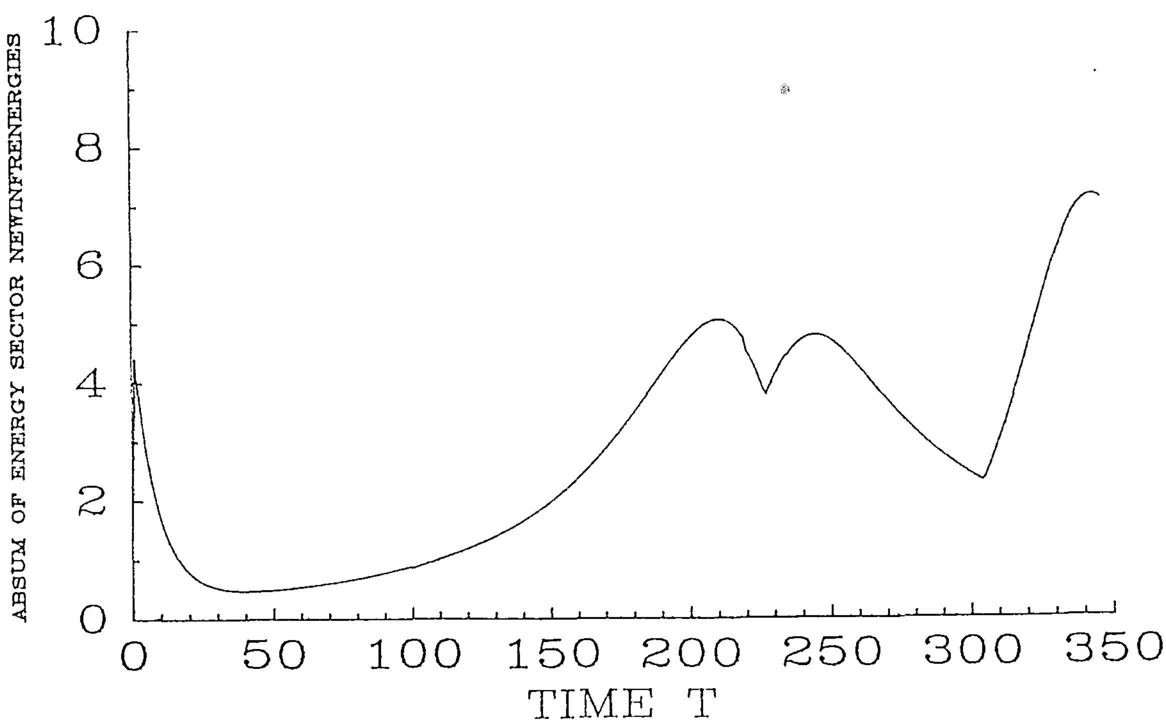


FIGURE 82 - CONSUMER SECTOR INFRASTRUCTURE - 0.1%

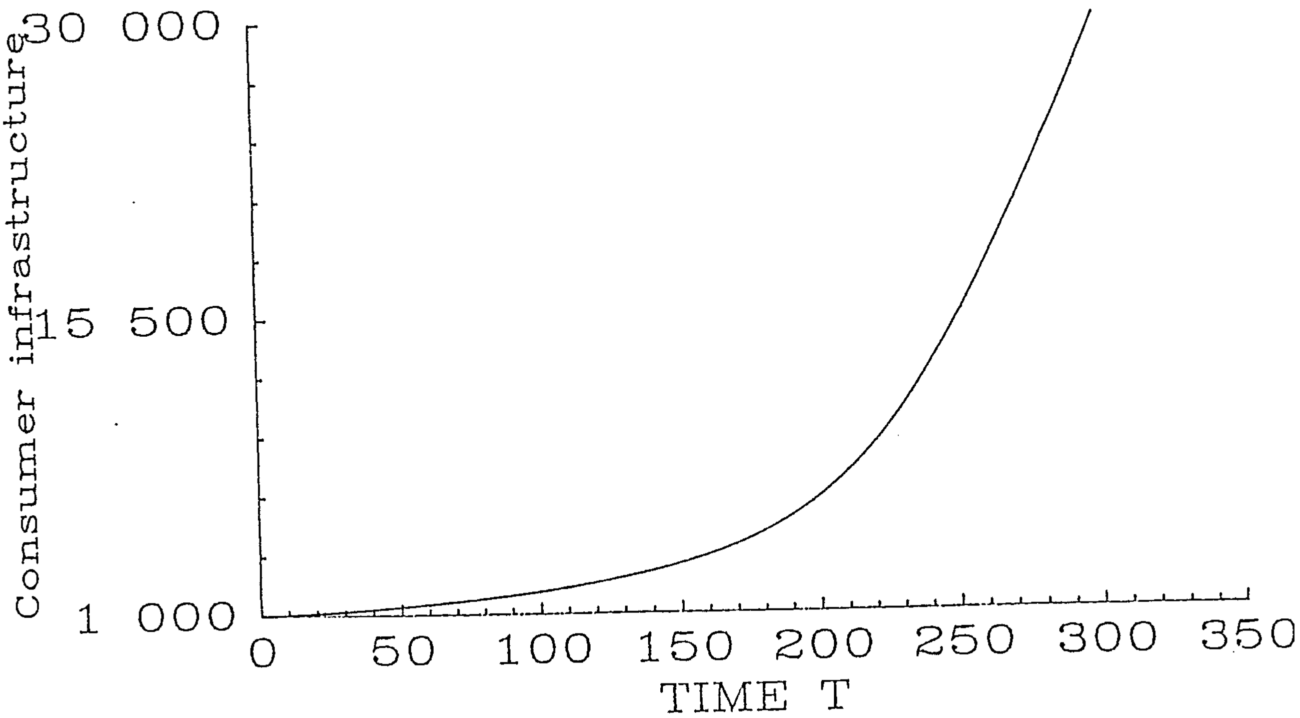


FIGURE 83 - NEW INFRASTURCTURE ADDED TO THE ENERGY REFINING INDUSTRY 0.1%

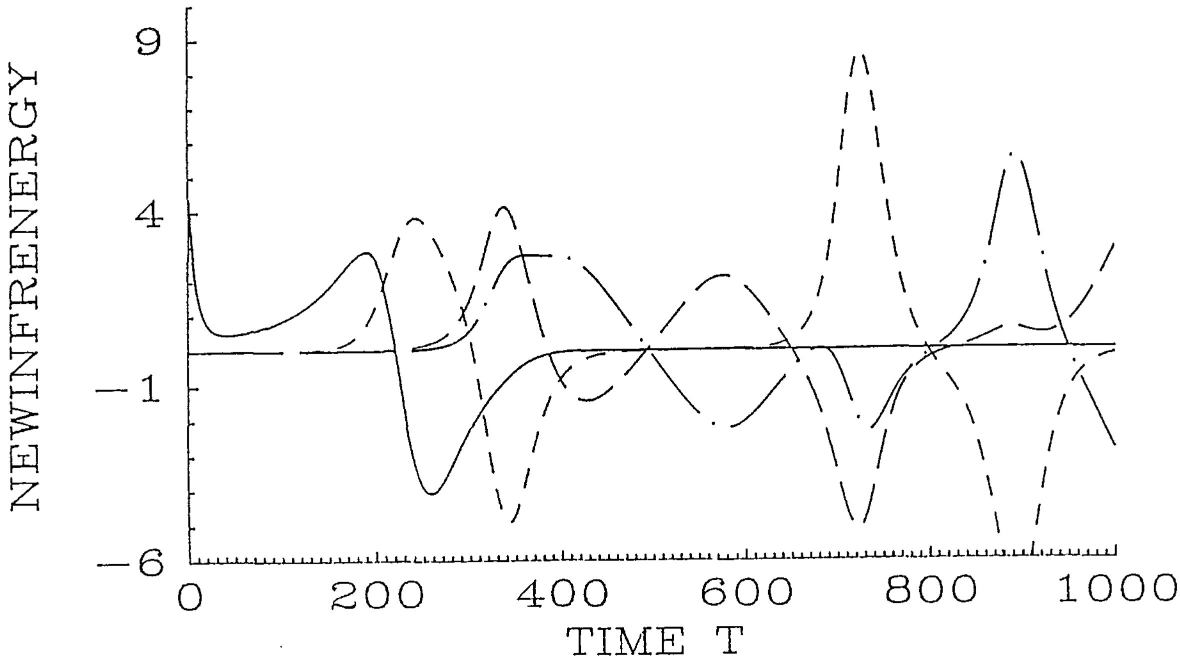


FIGURE 84 - SUM OF THE ENERGY SECTOR INFRASTRUCTURES 0.1%

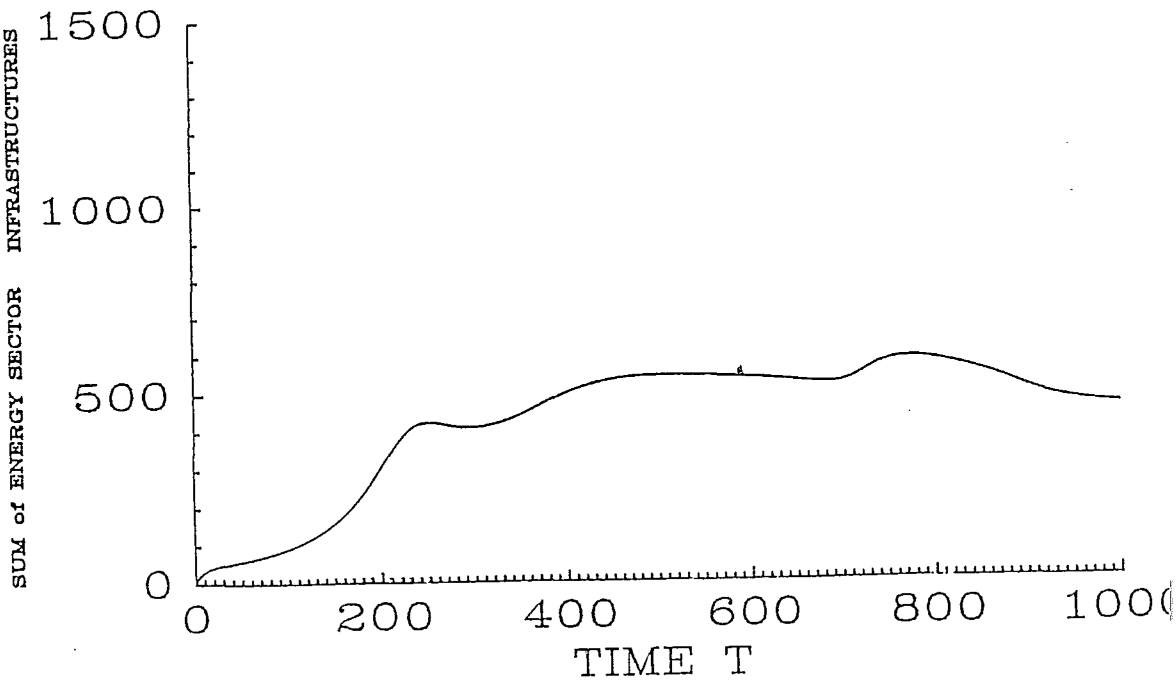


FIGURE 85 - ABSOLUTE SUM OF ENERGY SECTOR NEW INFRASTRUCTURES - 0.1%

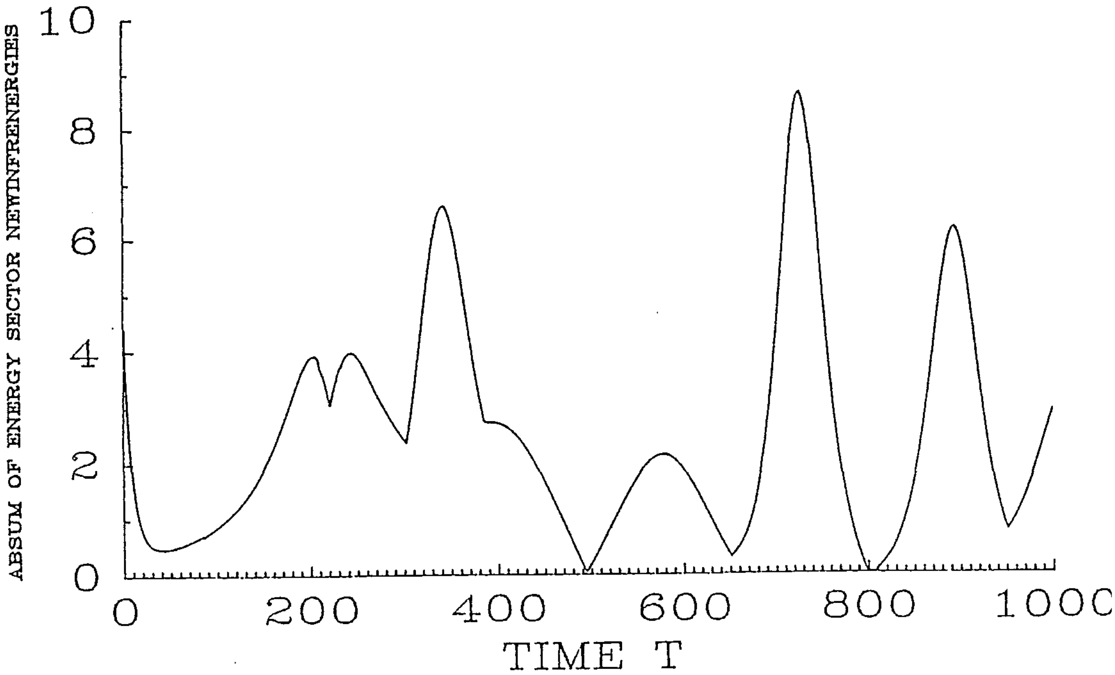


FIGURE 86 - SUM OF ENERGY SECTOR NEW INFRASTRUCTURES - 0.1%

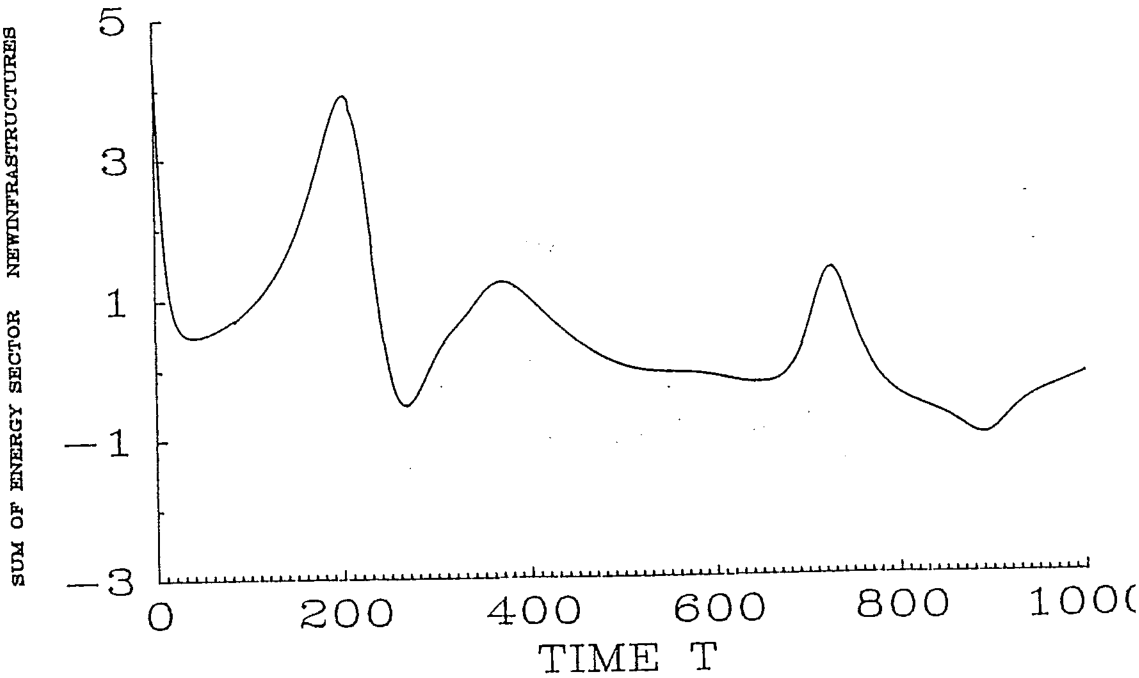


FIGURE 87 - ENVIRONMENTAL STOCK RESOURCES AND FLOW SOURCE FOR THE ENERGY SUPPLY SECTOR

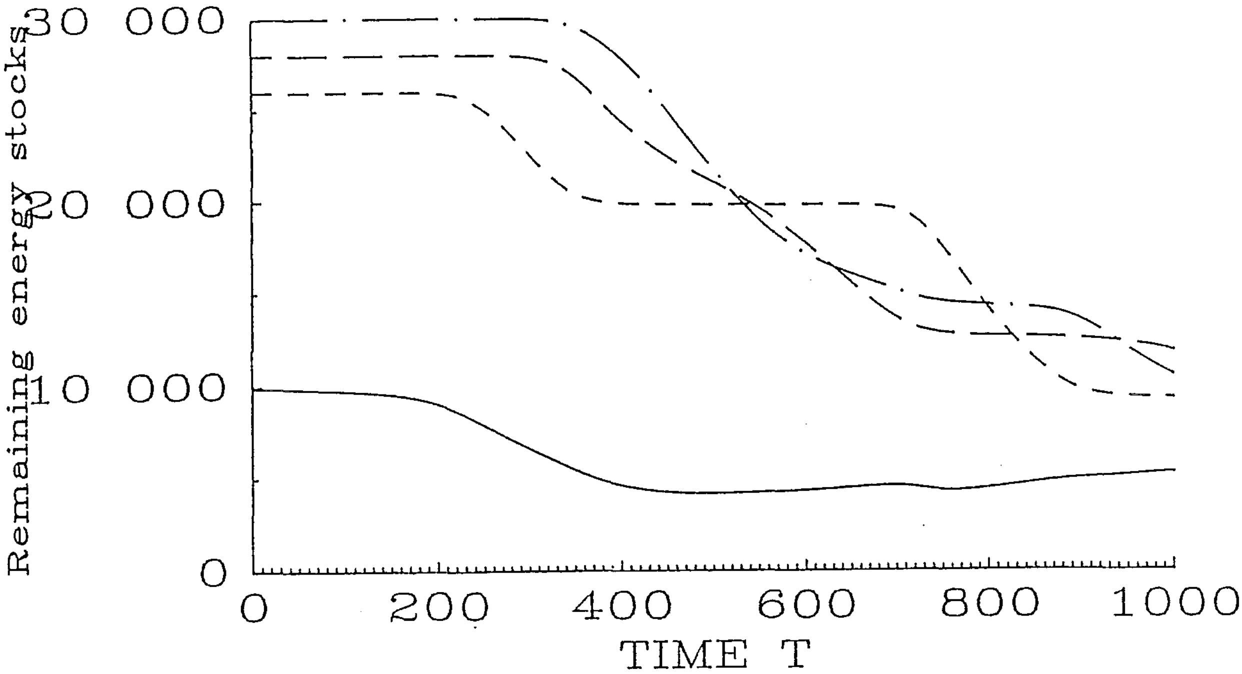
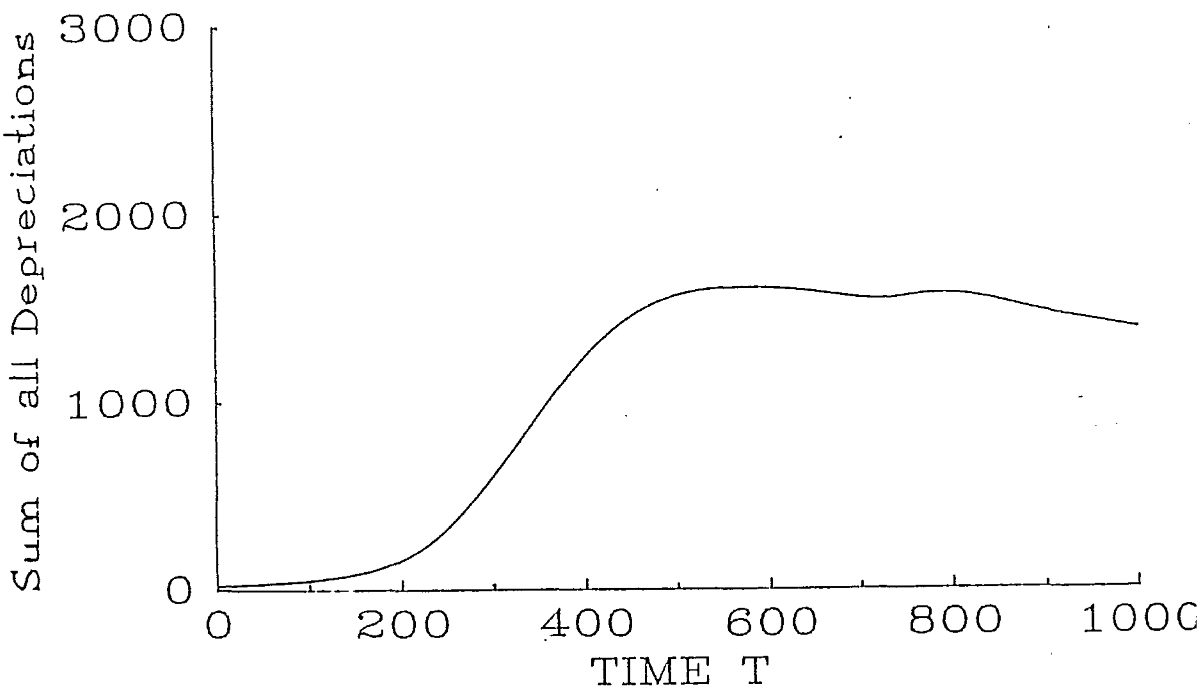


FIGURE 88 - THE AGGREGATE OF THE ENERGY SECTOR AND CONSUMER SECTOR DEPRECIATIONS



Appendix E

Computer Simulation Programs.

The following programs are used in the computer simulation of the Dynamic Energy Systems Model, the results of which are in this report.

The programs are labelled Energy 12, Energy 16, Energy 17 and Energy 18. They are similar to each other, but all have slight differences. Energy 12 is used to simulate the Marchetti data (4 sectors) at the 0.1% inception level. The programs used for the 2 and 3 sector cases which include a flow source are the same as Energy 12, but the input file is changed to read in only the sectors desired. Energy 16 has an inception time differential, and is used for just 2 stock sectors. Energy 17 is the same as Energy 16 except it has equal inception times. Energy 18 is used for simulating 1 stock sector. NONSOLETOT is set to 1000 in these latter 3 programs - it is read from an input file. It was previously set to 100 for the other programs, however, it was necessary to increase this when simulating 2 stock sectors, to stop a runaway growth effect, and consequent numerical overload.

An input file is also shown.

ENERGY 12. (Fortran).

```
IMPLICIT REAL (A-Z)
!Program to investigate the dynamics associated with an energy
!substitution sequence.
!
DIMENSION ACCESS(6),ACCESSORIGINAL(6),DEP(6),FFESR(6),OPEFBK(6),P(6)

DIMENSION O(6),E(6),FO(6),INCEPTDATE(6),CHANGE(6),NEWINFRENERGYO(6)
DIMENSION G(6),NEWINFRENERGY(6),H(6),CONSUMERFBK(6),K(6),L(6),N(6)
DIMENSION QUOTA(6),R(6),ECINFR(6),NONSOLARSHARE(6),TOTALSHARE(6)
INTEGER T,V,B,TMAX
!
!Definition of terms
!------------------------------------------------------------------------
!V = subscript variable
!T = programme iteration number
!ACCESS(V) = accessibility in each energy supply industry
!N.B. This does not include the depreciation term at present
!ACCESSORIGINAL(V) = original values of accessibility,ACCESS(V)
!ACCESSAVERAGE = consumption-related weighted average accessibility
!B = counter designating the number of energy supply sectors active
!NETCOUTPUT = gross output of consumer sector less inputs to energy
!supply sectors
!CHANGE(V) = relative change in energy sector infrastructures, given
!by NEWINFRENERGY(V)/ECINFR(V)
!NEWINFRCONSUMER = new infrastructure in consumer sector
!DEPC,DEP(V) = physical depreciation of structure in consumer and
!energy supply sectors
!FFESR(V),FFEFS = primary energy fluxes from environment to each
!energy supply sector
!OPCONSFBK,OPEFBK(V) = operating feedbacks in consumer and energy
!supply sectors
!FO(V) = alternative statement of market share,i.e. W(V)/(1-W(V))
!G(V)= flow coefficients for energy yields from energy supply
!sectors, E(V)
!GG = flow coefficient for gross output of consumer sector
!NEWINFRTOT = total new infrastructure in energy supply sectors
!NEWINFRENERGY(V) = new infrastructure in each energy supply sector
!NEWINFRENERGYO(V) = 0 if NEWINFRENERGY(V).LE.0
!H,H(V) = flow coefficients for operating feedbacks in consumer and
!energy supply sectors, OPCONSFBK,OPEFBK(V)
!FTOT,CONSUMERFBK(V) = total resource inputs from consumer sector
!to energy supply sectors
!EFS = total solar flux available for capture
!K,K(V) = flow coefficients for primary energy fluxes, DIRECT,FFESR(V)
!and FFEFS
!L,L(V) = flow coefficients for physical depreciation flows, DEPC,DEP(V)
!COMM = total non-solar flow of energy used in consumer sector activity
!COMMO = value of COMM from previous iteration
!N(V) = original values of H(V)
!O(V) = original values of R(V)
!INCEPTDATE(V) = date of inception of energy supply sectors
!GS = gross output of consumer sector
!QUOTA(V) = proportional quotas for resource inputs from consumer sector
!to each energy supply sector,OPEFBK(V)
!R(V) = remaining (untapped) flow and stocks of primary energy
!ECINFRC,ECINFR(V) = accumulated infrastructure in consumer and
!energy supply sectors
!NONSOLARSHARE(V) = non-solar market shares of energy yields, E(V)
!TOTALSHARE(V) = total energy market shares,i.e. including direct solar
!yield, DIRECT
!E(V) = energy supply sector yields to the consumer sector
!NONSOLETOT = total non-solar energy supply market
!DIRECT = primary solar energy flux in current use
!ETOT = total energy consumed,i.e. DIRECT + E(V)
!
!------------------------------------------------------------------------
!
        !Initial storage values for computing flow coefficients
!
OPEN(UNIT=3,FILE='A.LIS',READONLY,STATUS='OLD')
DO V=1,4
READ(3,*) R(V),INCEPTDATE(V),ACCESSORIGINAL(V)
O(V)=R(V)
END DO
READ(3,*) NONSOLETOT,ECINFRC,COMM,OPCONSFBK,DEPC,GS,
C EFS,DIRECT,E(1)
READ(3,*,END=640) TMAX
REWIND(3)
!
! Initialise flows in first supply sector
```

```
        OPEFBK(1) = E(1)/ACCESSORIGINAL(1)
        FFEFS = 1.7*E(1)
        ECINFR(1) = 5*E(1)
        DEP(1) = 0.5

       !Compute initial flow coefficients
       !
 0      HH=OPCONSFBK/(NONSOLETOT*ECINFRC*R(1))
 0      LL=DEPC/ECINFRC
 0      GG=GS/(NONSOLETOT*ECINFRC*R(1))
 0      KK=DIRECT/(NONSOLETOT*ECINFRC*R(1))
 0      K(1)=FFEFS/(R(1)*ECINFR(1))
 0      H(1)=OPEFBK(1)/(R(1)*ECINFR(1))
 0      N(1)=H(1)
 0      L(1)=DEP(1)/ECINFR(1)
 0      G(1)=E(1)/(R(1)*ECINFR(1))
       !
       !
       !Iterative loop
       !
       !Designate the number of energy sectors active   !
       !
 80     B=1
 90     DO T=1,TMAX+1
 00     ACCESSAVERAGE=0
 20     DO V=1,4
 30     IF (T.EQ.INCEPTDATE(V)) GOTO 1300
 40     END DO
 50     GOTO 1760
 00     B=B+1
       !
       !Initialise flows in new supply sector
       ! 0.1% inception
       !
 40     E(B)=0.001/0.999*COMM
 50     OPEFBK(B)=E(B)/ACCESSORIGINAL(B)
 60     FFESR(B)=1.7*E(B)
 70     ECINFR(B)=5*E(B)
 80     DEP(B)=0.22*ECINFR(B)
       !
       !Calculate flow coefficients for new supply sector
       !
 20     K(B)=FFESR(B)/(ECINFR(B)*R(B))
 30     H(B)=OPEFBK(B)/(ECINFR(B)*R(B))
 40     N(B)=H(B)
 50     L(B)=DEP(B)/ECINFR(B)
 60     G(B)=E(B)/(ECINFR(B)*R(B))
       !
       !Calculate Energy parameters
       !
 40     COMMO=0
        DO V=1,B
        COMMO=COMMO+E(V)
        END DO
        ETOT=DIRECT + COMMO
 70     DO V=1,B
 80     NONSOLARSHARE(V)=E(V)/COMMO
 85     FO(V)=NONSOLARSHARE(V)/(1.01-NONSOLARSHARE(V))
 90     ACCESS(V)=E(V)/OPEFBK(V)
 00     ACCESSAVERAGE=ACCESSAVERAGE+ACCESS(V)*NONSOLARSHARE(V)
 10     END DO
 20     DO V=1,B
 30     TOTALSHARE(V)=E(V)/ETOT
 40     QUOTA(V)=ACCESS(V)*NONSOLARSHARE(V)/ACCESSAVERAGE
 50     END DO
       !
       !Calculate consumer sector flows
       !
 30     OPCONSFBK=HH*NONSOLETOT*ECINFRC*R(1)
 40     DEPC=LL*ECINFRC
 50     GS=GG*NONSOLETOT*ECINFRC*R(1)
 60     FTOT=(0.5/ACCESSAVERAGE)*GS
 70     NETCOUTPUT=GS-FTOT
 80     NEWINFRCONSUMER=NETCOUTPUT-OPCONSFBK-DEPC
 90     DO V=1,B
 00     CONSUMERFBK(V)=QUOTA(V)*FTOT
 10     END DO
       !
       !Increment consumer sector storage
       !
```

```
50      ECINFRC=ECINFRC+NEWINFRCONSUMER
        !
        !Adjust accessibilities; i.e. flow coefficients designated H(V)
        !
00      GOTO 2270
10      DO V=2,B
20      H(V)=N(V)*O(V)/R(V)
30      END DO
        !
        !Calculate energy sector flows
        !
70      DIRECT=KK*NONSOLETOT*ECINFRC*EFS/(1+KK*NONSOLETOT*ECINFRC+K(1)
   C    *ECINFR(1))
80      FFEFS=K(1)*ECINFR(1)*EFS/(1+KK*NONSOLETOT*ECINFRC+K(1)*ECINFR(1))
90      IF (T.LT.INCEPTDATE(2)) GOTO 2330
00      DO V=2,B
10      FFESR(V)=K(V)*ECINFR(V)*R(V)
20      END DO
30      DO V=1,B
40      OPEFBK(V)=H(V)*ECINFR(V)*R(V)
50      DEP(V)=L(V)*ECINFR(V)
60      E(V)=G(V)*ECINFR(V)*R(V)
70      NEWINFRENERGY(V)=CONSUMERFBK(V)-OPEFBK(V)-DEP(V)
80      END DO
90      NEWINFRTOT=0
00      DO V=1,B
10      NEWINFRTOT=NEWINFRTOT+NEWINFRENERGY(V)
20      END DO
        !
        !Increment energy sector storages and energy market storage
        !
60      R(1)=EFS-DIRECT-FFEFS
70      IF (T.LT.INCEPTDATE(2)) GOTO 2505
80      DO V=2,B
90      R(V)=R(V)-FFESR(V)
00      END DO
        !
        !This loop calculates the relative change in sector infrastructures
        !and updates them by adding the new infrastructures.
        !
05      COMM=0
        DO V=1,B
30      ECINFR(V)=ECINFR(V)+NEWINFRENERGY(V)
        CHANGE(V) = NEWINFRENERGY(V)/ECINFR(V)
        COMM=COMM+E(V)
50      END DO
        !
        ! SUM IS THE SUM OF THE +VE ONLY VALUES OF NEWINFRENERGY(V)
        !
55      SUM=0
        DO V=1,B
        NEWINFRENERGYO(V) = NEWINFRENERGY(V)
        IF (NEWINFRENERGYO(V).LE.0) NEWINFRENERGYO(V) = 0
        SUM = SUM + NEWINFRENERGYO(V)
        END DO
60      NONSOLETOT=NONSOLETOT+COMM-COMMO
00      PRINT 506,FLOAT(T),COMM,SUM
30      PRINT 507,(NEWINFRENERGY(V),V=1,4)
50      PRINT 507,(NONSOLARSHARE(V),V=1,4)
00      PRINT 507,(ECINFR(V),V=1,4)
10      PRINT 507,(E(V),V=1,4)
20      PRINT 507,(DEP(V),V=1,4)
30      PRINT 507,(ACCESS(V),V=1,4)
40      PRINT 507,(QUOTA(V),V=1,4)
50      PRINT 507,(R(V),V=1,4)
60      PRINT 507,(TOTALSHARE(V),V=1,4)
70      PRINT 507,(OPEFBK(V),V=1,4)
80      PRINT 507,(CONSUMERFBK(V),V=1,4)
90      PRINT 507,(FO(V),V=1,4)
00      PRINT 507,FFEFS,FFESR(2),FFESR(3),FFESR(4)
10      PRINT 507,(G(V),V=1,4)
20      PRINT 507,(H(V),V=1,4)
30      PRINT 507,(K(V),V=1,4)
40      PRINT 507,(L(V),V=1,4)
50      PRINT 507,GS,NEWINFRTOT,ECINFRC,NEWINFRCONSUMER,ACCESSAVERAGE
60      PRINT 507,DEPC,DIRECT,D$CONSFBK,COMMO,NONSOLETOT
70      PRINT 507,(CHANGE(V),V=1,4)
06      FORMAT(F11.1,2F11.5)
07      FORMAT(5F15.5)
00      END DO
```

```
      IMPLICIT REAL (A-Z)
      !Program to investigate the dynamics associated with an energy
      !substitution sequence.
      !
      DIMENSION ACCESS(6),ACCESSORIGINAL(6),DEP(6),FFESR(6),OPEFBK(6),P(6)

      DIMENSION O(6),E(6),FO(6),INCEPTDATE(6),CHANGE(6),NEWINFRENERGYO(6)
      DIMENSION G(6),NEWINFRENERGY(6),H(6),CONSUMERFBK(6),K(6),L(6),N(6)
      DIMENSION QUOTA(6),R(6),ECINFR(6),NONSOLARSHARE(6),TOTALSHARE(6)
      INTEGER T,V,B,TMAX
      !
      !Definition of terms
      !------------------------------------------------------------------------
      !V = subscript variable
      !T = programme iteration number
      !ACCESS(V) = accessibility in each energy supply industry
      !N.B. This does not include the depreciation term at present
      !ACCESSORIGINAL(V) = original values of accessibility,ACCESS(V)
      !ACCESSAVERAGE = consumption-related weighted average accessibility
      !B = counter designating the number of energy supply sectors active
      !NETCOUTPUT = gross output of consumer sector less inputs to energy
      !supply sectors
      !CHANGE(V) = relative change in energy sector infrastructures, given
      !by NEWINFRENERGY(V)/ECINFR(V)
      !NEWINFRCONSUMER = new infrastructure in consumer sector
      !DEPC,DEP(V) = physical depreciation of structure in consumer and
      !energy supply sectors
      !FFESR(V),FFEFS = primary energy fluxes from environment to each
      !energy supply sector
      !OPCONSFBK,OPEFBK(V) = operating feedbacks in consumer and energy
      !supply sectors
      !FO(V) = alternative statement of market share,i.e. W(V)/(1-W(V))
      !G(V)= flow coefficients for energy yields from energy supply
      !sectors, E(V)
      !GG = flow coefficient for gross output of consumer sector
      !NEWINFRTOT = total new infrastructure in energy supply sectors
      !NEWINFRENERGY(V) = new infrastructure in each energy supply sector
      !NEWINFRENERGYO(V) = 0 if NEWINFRENERGY(V).LE.0
      !H,H(V) = flow coefficients for operating feedbacks in consumer and
      !energy supply sectors, OPCONSFBK,OPEFBK(V)
      !FTOT,CONSUMERFBK(V) = total resource inputs from consumer sector
      !to energy supply sectors
      !EFS = total solar flux available for capture
      !K,K(V) = flow coefficients for primary energy fluxes, DIRECT,FFESR(V)
      !and FFEFS
      !L,L(V) = flow coefficients for physical depreciation flows, DEPC,DEP(V)
      !COMM = total non-solar flow of energy used in consumer sector activity
      !COMMO = value of COMM from previous iteration
      !N(V) = original values of H(V)
      !O(V) = original values of R(V)
      !INCEPTDATE(V) = date of inception of energy supply sectors
      !GS = gross output of consumer sector
      !QUOTA(V) = proportional quotas for resource inputs from consumer sector
      !to each energy supply sector,OPEFBK(V)
      !R(V) = remaining (untapped) flow and stocks of primary energy
      !ECINFRC,ECINFR(V) = accumulated infrastructure in consumer and
      !energy supply sectors
      !NONSOLARSHARE(V) = non-solar market shares of energy yields, E(V)
      !TOTALSHARE(V) = total energy market shares,i.e. including direct solar
      !yield, DIRECT
      !E(V) = energy supply sector yields to the consumer sector
      !NONSOLETOT = total non-solar energy supply market
      !DIRECT = primary solar energy flux in current use
      !ETOT = total energy consumed,i.e. DIRECT + E(V)
      !
      !------------------------------------------------------------------------
      !This program is for 2 sectors only.
              !Initial storage values for computing flow coefficients
      !
      OPEN(UNIT=3,FILE='A.LIS',READONLY,STATUS='OLD')
      DO V=1,2
      READ(3,*) R(V),INCEPTDATE(V),ACCESSORIGINAL(V)
      O(V)=R(V)
      END DO
      READ(3,*) NONSOLETOT,ECINFRC,COMM,OPCONSFBK,DEPC,GS,
     C EFS,DIRECT,E(1)
      READ(3,*,END=640) TMAX
      REWIND(3)
      !
      ! Initialise flows in first supply sector
```

```
      OPEFBK(1) = E(1)/ACCESSORIGINAL(1)
      FFESR(1) = 1.1*E(1)
      ECINFR(1) = 5*E(1)
      DEP(1) = 0.22*ECINFR(1)

      !Compute initial flow coefficients
      !These equations have R(1) taken out of them
      !HH, GG and KK.
      HH=OPCONSFBK/(NONSOLETOT*ECINFRC)
      LL=DEPC/ECINFRC
      GG=GS/(NONSOLETOT*ECINFRC)
      KK=DIRECT/(NONSOLETOT*ECINFRC)
      K(1)=FFESR(1)/(R(1)*ECINFR(1))
      H(1)=OPEFBK(1)/(R(1)*ECINFR(1))
      N(1)=H(1)
      L(1)=DEP(1)/ECINFR(1)
      G(1)=E(1)/(R(1)*ECINFR(1))
      !
      !
      !Iterative loop
      !
      !Designate the number of energy sectors active    !
      !
      B=1
      DO T=1,TMAX+1
      ACCESSAVERAGE=0
      DO V=1,2
      IF (T.EQ.INCEPTDATE(V)) GOTO 1300
      END DO
      GOTO 1760
      B=B+1
      !
      !Initialise flows in new supply sector
      ! 0.1% inception
      !
      E(B)=0.001/0.999*COMM
      OPEFBK(B)=E(B)/ACCESSORIGINAL(B)
      FFESR(B)=1.1*E(B)
      ECINFR(B)=5*E(B)
      DEP(B)=0.22*ECINFR(B)
      !
      !Calculate flow coefficients for new supply sector
      !
      K(B)=FFESR(B)/(ECINFR(B)*R(B))
      H(B)=OPEFBK(B)/(ECINFR(B)*R(B))
      N(B)=H(B)
      L(B)=DEP(B)/ECINFR(B)
      G(B)=E(B)/(ECINFR(B)*R(B))
      !
      !Calculate Energy parameters
      !
      COMMO=0
      DO V=1,B
      COMMO=COMMO+E(V)
      END DO
      ETOT=DIRECT + COMMO
      DO V=1,B
      NONSOLARSHARE(V)=E(V)/COMMO
      FO(V)=NONSOLARSHARE(V)/(1.01-NONSOLARSHARE(V))
      ACCESS(V)=E(V)/OPEFBK(V)
      ACCESSAVERAGE=ACCESSAVERAGE+ACCESS(V)*NONSOLARSHARE(V)
      END DO
      DO V=1,B
      TOTALSHARE(V)=E(V)/ETOT
      QUOTA(V)=ACCESS(V)*NONSOLARSHARE(V)/ACCESSAVERAGE
      END DO
      !
      !Calculate consumer sector flows
      !These equations have R(1) taken out of them
      !OPCONSFBK, and GS.
      OPCONSFBK=HH*NONSOLETOT*ECINFRC
      DEPC=LL*ECINFRC
      GS=GG*NONSOLETOT*ECINFRC
      FTOT=(0.5/ACCESSAVERAGE)*GS
      NETCOUTPUT=GS-FTOT
      NEWINFRCONSUMER=NETCOUTPUT-OPCONSFBK-DEPC
      DO V=1,B
      CONSUMERFBK(V)=QUOTA(V)*FTOT
      END DO
      !
```

```
       !Increment consumer sector storage
       !
0      ECINFRC=ECINFRC+NEWINFRCONSUMER
       !
       !Adjust accessibilities; i.e. flow coefficients designated H(V)
       !
0      DO V=1,B
0      H(V)=N(V)*O(V)/R(V)
0      END DO
       !
       !Calculate energy sector flows
       !
       !DIRECT=KK*NONSOLETOT*ECINFRC*EFS/(1+KK*NONSOLETOT*ECINFRC+K(1)
       !c     *ECINFR(1))
       !FFEFS=K(1)*ECINFR(1)*EFS/(1+KK*NONSOLETOT*ECINFRC+K(1)*ECINFR(1))
       !IF  (T.LT.INCEPTDATE(2))  GOTO 2330
0      DO V=1,B
0      FFESR(V)=K(V)*ECINFR(V)*R(V)
0      END DO
0      DO V=1,B
0      OPEFBK(V)=H(V)*ECINFR(V)*R(V)
0      DEP(V)=L(V)*ECINFR(V)
0      E(V)=G(V)*ECINFR(V)*R(V)
0      NEWINFRENERGY(V)=CONSUMERFBK(V)-OPEFBK(V)-DEP(V)
0      END DO
0      NEWINFRTOT=0
0      DO V=1,B
0      NEWINFRTOT=NEWINFRTOT+NEWINFRENERGY(V)
0      END DO
       !
       !Increment energy sector storages and energy market storage
       !
       !R(1)=EFS-DIRECT-FFEFS
       !IF  (T.LT.INCEPTDATE(2))  GOTO 2505
0      DO V=1,B
0      R(V)=R(V)-FFESR(V)
0      END DO
       !
       !This loop calculates the relative change in sector infrastructures
       !and updates them by adding the new infrastructures.
       !
5      COMM=0
       DO V=1,B
0      ECINFR(V)=ECINFR(V)+NEWINFRENERGY(V)
       CHANGE(V) = NEWINFRENERGY(V)/ECINFR(V)
       COMM=COMM+E(V)
0      END DO
       !
       ! SUM IS THE SUM OF THE +VE ONLY VALUES OF NEWINFRENERGY(V)
       !
5      SUM=0
       DO V=1,B
       NEWINFRENERGYO(V) = NEWINFRENERGY(V)
       IF  (NEWINFRENERGYO(V).LE.0)  NEWINFRENERGYO(V)  = 0
       SUM = SUM + NEWINFRENERGYO(V)
       END DO
0      NONSOLETOT=NONSOLETOT+COMM-COMMO
0      PRINT 506,FLOAT(T),COMM,SUM
0      PRINT 507,(NEWINFRENERGY(V),V=1,5)
0      PRINT 507,(NONSOLARSHARE(V),V=1,5)
0      PRINT 507,(ECINFR(V),V=1,5)
0      PRINT 507,(E(V),V=1,5)
0      PRINT 507,(DEP(V),V=1,5)
0      PRINT 507,(ACCESS(V),V=1,5)
0      PRINT 507,(QUOTA(V),V=1,5)
0      PRINT 507,(R(V),V=1,5)
0      PRINT 507,(TOTALSHARE(V),V=1,5)
0      PRINT 507,(OPEFBK(V),V=1,5)
0      PRINT 507,(CONSUMERFBK(V),V=1,5)
0      PRINT 507,(FO(V),V=1,5)
0      PRINT 507,FFESR(1),FFESR(2),FFESR(3),FFESR(4),FFESR(5)
0      PRINT 507,(G(V),V=1,5)
0      PRINT 507,(H(V),V=1,5)
0      PRINT 507,(K(V),V=1,5)
0      PRINT 507,(L(V),V=1,5)
0      PRINT 507,GS,NEWINFRTOT,ECINFRC,NEWINFRCONSUMER,ACCESSAVERAGE
0      PRINT 507,DEPC,DIRECT,OPCONSFBK,COMMO,NONSOLETOT
0      PRINT 507,(CHANGE(V),V=1,5)
       FORMAT(E14.5,2E14.5)
       FORMAT(5E14.5)
```

```
      IMPLICIT REAL (A-Z)
      !Program to investigate the dynamics associated with an energy
      !substitution sequence.
      !
      DIMENSION ACCESS(6),ACCESSORIGINAL(6),DEP(6),FFESR(6),OPEFBK(6),P(6)

      DIMENSION O(6),E(6),FO(6),INCEPTDATE(6),CHANGE(6),NEWINFRENERGYO(6)
      DIMENSION G(6),NEWINFRENERGY(6),H(6),CONSUMERFBK(6),K(6),L(6),N(6)
      DIMENSION QUOTA(6),R(6),ECINFR(6),NONSOLARSHARE(6),TOTALSHARE(6)
      INTEGER T,V,B,TMAX
      !
      !Definition of terms
      !-----------------------------------------------------------------------
      !V = subscript variable
      !T = programme iteration number
      !ACCESS(V) = accessibility in each energy supply industry
      !N.B. This does not include the depreciation term at present
      !ACCESSORIGINAL(V) = original values of accessibility,ACCESS(V)
      !ACCESSAVERAGE = consumption-related weighted average accessibility
      !B = counter designating the number of energy supply sectors active
      !NETCOUTPUT = gross output of consumer sector less inputs to energy
      !supply sectors
      !CHANGE(V) = relative change in energy sector infrastructures, given
      !by NEWINFRENERGY(V)/ECINFR(V)
      !NEWINFRCONSUMER = new infrastructure in consumer sector
      !DEPC,DEP(V) = physical depreciation of structure in consumer and
      !energy supply sectors
      !FFESR(V),FFEFS = primary energy fluxes from environment to each
      !energy supply sector
      !OPCONSFBK,OPEFBK(V) = operating feedbacks in consumer and energy
      !supply sectors
      !FO(V) = alternative statement of market share,i.e. W(V)/(1-W(V))
      !G(V)= flow coefficients for energy yields from energy supply
      !sectors, E(V)
      !GG = flow coefficient for gross output of consumer sector
      !NEWINFRTOT = total new infrastructure in energy supply sectors
      !NEWINFRENERGY(V) = new infrastructure in each energy supply sector
      !NEWINFRENERGYO(V) = 0 if NEWINFRENERGY(V).LE.0
      !H,H(V) = flow coefficients for operating feedbacks in consumer and
      !energy supply sectors, OPCONSFBK,OPEFBK(V)
      !FTOT,CONSUMERFBK(V) = total resource inputs from consumer sector
      !to energy supply sectors
      !EFS = total solar flux available for capture
      !K,K(V) = flow coefficients for primary energy fluxes, DIRECT,FFESR(V)
      !and FFEFS
      !L,L(V) = flow coefficients for physical depreciation flows, DEPC,DEP(V)
      !COMM = total non-solar flow of energy used in consumer sector activity
      !COMMO = value of COMM from previous iteration
      !N(V) = original values of H(V)
      !O(V) = original values of R(V)
      !INCEPTDATE(V) = date of inception of energy supply sectors
      !GS = gross output of consumer sector
      !QUOTA(V) = proportional quotas for resource inputs from consumer sector
      !to each energy supply sector,OPEFBK(V)
      !R(V) = remaining (untapped) flow and stocks of primary energy
      !ECINFRC,ECINFR(V) = accumulated infrastructure in consumer and
      !energy supply sectors
      !NONSOLARSHARE(V) = non-solar market shares of energy yields, E(V)
      !TOTALSHARE(V) = total energy market shares,i.e. including direct solar
      !yield, DIRECT
      !E(V) = energy supply sector yields to the consumer sector
      !NONSOLETOT = total non-solar energy supply market
      !DIRECT = primary solar energy flux in current use
      !ETOT = total energy consumed,i.e. DIRECT + E(V)
      !
      !-----------------------------------------------------------------------
      !This program is for 2 sectors only.
              !Initial storage values for computing flow coefficients
      !It is for equal inceptions only.
      OPEN(UNIT=3,FILE='A.LIS',READONLY,STATUS='OLD')
      DO V=1,2
      READ(3,*) R(V),INCEPTDATE(V),ACCESSORIGINAL(V)
      O(V)=R(V)
      END DO
      READ(3,*) NONSOLETOT,ECINFRC,COMM,OPCONSFBK,DEPC,GS,
     C EFS,DIRECT,E(1)
      READ(3,*,END=640) TMAX
      REWIND(3)
      !
      ! Initialise flows in supply sectors
```

```
      E(2) = E(1)
      DO V=1,2
      OPEFBK(V) = E(V)/ACCESSORIGINAL(V)
      FFESR(V) = 1.1*E(V)
      ECINFR(V) = 5*E(V)
      DEP(V) = 0.22*ECINFR(V)

      !Compute initial flow coefficients
      !These equations have R(1) taken out of them
      !HH, GG and KK.
      HH=OPCONSFBK/(NONSOLETOT*ECINFRC)
      LL=DEPC/ECINFRC
      GG=GS/(NONSOLETOT*ECINFRC)
      KK=DIRECT/(NONSOLETOT*ECINFRC)
      K(V)=FFESR(V)/(R(V)*ECINFR(V))
      H(V)=OPEFBK(V)/(R(V)*ECINFR(V))
      N(V)=H(V)
      L(V)=DEP(V)/ECINFR(V)
      G(V)=E(V)/(R(V)*ECINFR(V))
      END DO
      !
      !
      !Iterative loop
      !
      !Designate the number of energy sectors active  !
      !
      B=2
      DO T=0,TMAX
      ACCESSAVERAGE=0
      !
      !
      !Calculate Energy parameters
      !
      COMMO=0
      DO V=1,B
      COMMO=COMMO+E(V)
      END DO
      ETOT=DIRECT + COMMO
      DO V=1,B
      NONSOLARSHARE(V)=E(V)/COMMO
      FO(V)=NONSOLARSHARE(V)/(1.01-NONSOLARSHARE(V))
      ACCESS(V)=E(V)/OPEFBK(V)
      ACCESSAVERAGE=ACCESSAVERAGE+ACCESS(V)*NONSOLARSHARE(V)
      END DO
      DO V=1,B
      TOTALSHARE(V)=E(V)/ETOT
      QUOTA(V)=ACCESS(V)*NONSOLARSHARE(V)/ACCESSAVERAGE
      END DO
      !
      !Calculate consumer sector flows
      !These equations have R(1) taken out of them
      !OPCONSFBK, and GS.
      OPCONSFBK=HH*NONSOLETOT*ECINFRC
      DEPC=LL*ECINFRC
      GS=GG*NONSOLETOT*ECINFRC
      FTOT=(0.5/ACCESSAVERAGE)*GS
      NETCOUTPUT=GS-FTOT
      NEWINFRCONSUMER=NETCOUTPUT-OPCONSFBK-DEPC
      DO V=1,B
      CONSUMERFBK(V)=QUOTA(V)*FTOT
      END DO
      !
      !Increment consumer sector storage
      !
      ECINFRC=ECINFRC+NEWINFRCONSUMER
      !
      !Adjust accessibilities; i.e. flow coefficients designated H(V)
      !
      GOTO 2300
      DO V=2,B
      H(V)=N(V)*O(V)/R(V)
      END DO
      !
      !Calculate energy sector flows
      !
      !DIRECT=KK*NONSOLETOT*ECINFRC*EFS/(1+KK*NONSOLETOT*ECINFRC+K(1)
      !c    *ECINFR(1))
      !FFEFS=K(1)*ECINFR(1)*EFS/(1+KK*NONSOLETOT*ECINFRC+K(1)*ECINFR(1))
      !IF (T.LT.INCEPTDATE(2)) GOTO 2330
      DO V=1,B
```

```
      FFESR(V)=K(V)*ECINFR(V)*R(V)
      END DO
      DO V=1,B
      OPEFBK(V)=H(V)*ECINFR(V)*R(V)
      DEP(V)=L(V)*ECINFR(V)
      E(V)=G(V)*ECINFR(V)*R(V)
      NEWINFRENERGY(V)=CONSUMERFBK(V)-OPEFBK(V)-DEP(V)
      END DO
      NEWINFRTOT=0
      DO V=1,B
      NEWINFRTOT=NEWINFRTOT+NEWINFRENERGY(V)
      END DO
      !
      !Increment energy sector storages and energy market storage
      !
      !R(1)=EFS-DIRECT-FFEFS
      !IF (T.LT.INCEPTDATE(2)) GOTO 2505
      DO V=1,B
      R(V)=R(V)-FFESR(V)
      END DO
      !
      !This loop calculates the relative change in sector infrastructures
      !and updates them by adding the new infrastructures.
      !
      COMM=0
      DO V=1,B
      ECINFR(V)=ECINFR(V)+NEWINFRENERGY(V)
      CHANGE(V) = NEWINFRENERGY(V)/ECINFR(V)
      COMM=COMM+E(V)
      END DO
      !
      ! SUM IS THE SUM OF THE +VE ONLY VALUES OF NEWINFRENERGY(V)
      !
      SUM=0
      DO V=1,B
      NEWINFRENERGYO(V) = NEWINFRENERGY(V)
      IF (NEWINFRENERGYO(V).LE.0) NEWINFRENERGYO(V) = 0
      SUM = SUM + NEWINFRENERGYO(V)
      END DO
      NONSOLETOT=NONSOLETOT+COMM-COMMO
      PRINT 506,FLOAT(T),COMM,SUM
      PRINT 507,(NEWINFRENERGY(V),V=1,5)
      PRINT 507,(NONSOLARSHARE(V),V=1,5)
      PRINT 507,(ECINFR(V),V=1,5)
      PRINT 507,(E(V),V=1,5)
      PRINT 507,(DEP(V),V=1,5)
      PRINT 507,(ACCESS(V),V=1,5)
      PRINT 507,(QUOTA(V),V=1,5)
      PRINT 507,(R(V),V=1,5)
      PRINT 507,(TOTALSHARE(V),V=1,5)
      PRINT 507,(OPEFBK(V),V=1,5)
      PRINT 507,(CONSUMERFBK(V),V=1,5)
      PRINT 507,(FO(V),V=1,5)
      PRINT 507,FFESR(1),FFESR(2),FFESR(3),FFESR(4),FFESR(5)
      PRINT 507,(G(V),V=1,5)
      PRINT 507,(H(V),V=1,5)
      PRINT 507,(K(V),V=1,5)
      PRINT 507,(L(V),V=1,5)
      PRINT 507,GS,NEWINFRTOT,ECINFRC,NEWINFRCONSUMER,ACCESSAVERAGE
      PRINT 507,DEPC,DIRECT,OPCONSFBK,COMMO,NONSOLETOT
      PRINT 507,(CHANGE(V),V=1,5)
      FORMAT(E14.5,2E14.5)
      FORMAT(5E14.5)
      END DO
      END
```

```
      IMPLICIT REAL (A-Z)
      !Program to investigate the dynamics associated with an energy
      !substitution sequence.
      !
      DIMENSION ACCESS(6),ACCESSORIGINAL(6),DEP(6),FFESR(6),OPEFBK(6),P(6)

      DIMENSION O(6),E(6),FO(6),INCEPTDATE(6),CHANGE(6),NEWINFRENERGYO(6)
      DIMENSION G(6),NEWINFRENERGY(6),H(6),CONSUMERFBK(6),K(6),L(6),N(6)
      DIMENSION QUOTA(6),R(6),ECINFR(6),NONSOLARSHARE(6),TOTALSHARE(6)
      INTEGER T,V,B,TMAX
      !
      !Definition of terms
      !-----------------------------------------------------------------------
      !V = subscript variable
      !T = programme iteration number
      !ACCESS(V) = accessibility in each energy supply industry
      !N.B. This does not include the depreciation term at present
      !ACCESSORIGINAL(V) = original values of accessibility,ACCESS(V)
      !ACCESSAVERAGE = consumption-related weighted average accessibility
      !B = counter designating the number of energy supply sectors active
      !NETCOUTPUT = gross output of consumer sector less inputs to energy
      !supply sectors
      !CHANGE(V) = relative change in energy sector infrastructures, given
      !by NEWINFRENERGY(V)/ECINFR(V)
      !NEWINFRCONSUMER = new infrastructure in consumer sector
      !DEPC,DEP(V) = physical depreciation of structure in consumer and
      !energy supply sectors
      !FFESR(V),FFEFS = primary energy fluxes from environment to each
      !energy supply sector
      !OPCONSFBK,OPEFBK(V) = operating feedbacks in consumer and energy
      !supply sectors
      !FO(V) = alternative statement of market share,i.e. W(V)/(1-W(V))
      !G(V)= flow coefficients for energy yields from energy supply
      !sectors, E(V)
      !GG = flow coefficient for gross output of consumer sector
      !NEWINFRTOT = total new infrastructure in energy supply sectors
      !NEWINFRENERGY(V) = new infrastructure in each energy supply sector
      !NEWINFRENERGYO(V) = 0 if NEWINFRENERGY(V).LE.0
      !H,H(V) = flow coefficients for operating feedbacks in consumer and
      !energy supply sectors, OPCONSFBK,OPEFBK(V)
      !FTOT,CONSUMERFBK(V) = total resource inputs from consumer sector
      !to energy supply sectors
      !EFS = total solar flux available for capture
      !K,K(V) = flow coefficients for primary energy fluxes, DIRECT,FFESR(V)
      !and FFEFS
      !L,L(V) = flow coefficients for physical depreciation flows, DEPC,DEP(V)
      !COMM = total non-solar flow of energy used in consumer sector activity
      !COMMO = value of COMM from previous iteration
      !N(V) = original values of H(V)
      !O(V) = original values of R(V)
      !INCEPTDATE(V) = date of inception of energy supply sectors
      !GS = gross output of consumer sector
      !QUOTA(V) = proportional quotas for resource inputs from consumer sector
      !to each energy supply sector,OPEFBK(V)
      !R(V) = remaining (untapped) flow and stocks of primary energy
      !ECINFRC,ECINFR(V) = accumulated infrastructure in consumer and
      !energy supply sectors
      !NONSOLARSHARE(V) = non-solar market shares of energy yields, E(V)
      !TOTALSHARE(V) = total energy market shares,i.e. including direct solar
      !yield, DIRECT
      !E(V) = energy supply sector yields to the consumer sector
      !NONSOLETOT = total non-solar energy supply market
      !DIRECT = primary solar energy flux in current use
      !ETOT = total energy consumed,i.e. DIRECT + E(V)
      !
      !-----------------------------------------------------------------------
      !This program is for 1 sector only.
              !Initial storage values for computing flow coefficients
      !
      OPEN(UNIT=3,FILE='A.LIS',READONLY,STATUS='OLD')
      DO V=1,1
      READ(3,*) R(V),INCEPTDATE(V),ACCESSORIGINAL(V)
      O(V)=R(V)
      END DO
      READ(3,*) NONSOLETOT,ECINFRC,COMM,OPCONSFBK,DEPC,GS,
    C EFS,DIRECT,E(1)
      READ(3,*,END=640) TMAX
      REWIND(3)
      !
      ! Initialise flows in supply sector
```

```
      DO V=1,1
      OPEFBK(V)  = E(V)/ACCESSORIGINAL(V)
      FFESR(V)  =  1.1*E(V)
      ECINFR(V)  =  5*E(V)
      DEP(V)  = 0.22*ECINFR(V)

      !Compute initial flow coefficients
      !These equations have R(1) taken out of them
      !HH, GG and KK.
      HH=OPCONSFBK/(NONSOLETOT*ECINFRC)
      LL=DEPC/ECINFRC
      GG=GS/(NONSOLETOT*ECINFRC)
      KK=DIRECT/(NONSOLETOT*ECINFRC)
      K(V)=FFESR(V)/(R(V)*ECINFR(V))
      H(V)=OPEFBK(V)/(R(V)*ECINFR(V))
      N(V)=H(V)
      L(V)=DEP(V)/ECINFR(V)
      G(V)=E(V)/(R(V)*ECINFR(V))
      END DO
            !
      !
      !Iterative loop
      !
      !Designate the number of energy sectors active   !
      !
      B=1
      DO T=0,TMAX
      ACCESSAVERAGE=0
      !
      !
      !Calculate Energy parameters
      !
      COMMO=0
      DO V=1,B
      COMMO=COMMO+E(V)
      END DO
      ETOT=DIRECT + COMMO
      DO V=1,B
      NONSOLARSHARE(V)=E(V)/COMMO
      FO(V)=NONSOLARSHARE(V)/(1.01-NONSOLARSHARE(V))
      ACCESS(V)=E(V)/OPEFBK(V)
      ACCESSAVERAGE=ACCESSAVERAGE+ACCESS(V)*NONSOLARSHARE(V)
      END DO
      DO V=1,B
      TOTALSHARE(V)=E(V)/ETOT
      QUOTA(V)=ACCESS(V)*NONSOLARSHARE(V)/ACCESSAVERAGE
      END DO
      !
      !Calculate consumer sector flows
      !These equations have R(1) taken out of them
      !OPCONSFBK, and GS.
      OPCONSFBK=HH*NONSOLETOT*ECINFRC
      DEPC=LL*ECINFRC
      GS=GG*NONSOLETOT*ECINFRC
      FTOT=(0.5/ACCESSAVERAGE)*GS
      NETCOUTPUT=GS-FTOT
      NEWINFRCONSUMER=NETCOUTPUT-OPCONSFBK-DEPC
      DO V=1,B
      CONSUMERFBK(V)=QUOTA(V)*FTOT
      END DO
      !
      !Increment consumer sector storage
      !
      ECINFRC=ECINFRC+NEWINFRCONSUMER
      !
      !Adjust accessibilities; i.e. flow coefficients designated H(V)
      !
      GOTO 2300
      DO V=2,B
      H(V)=N(V)*O(V)/R(V)
      END DO
      !
      !Calculate energy sector flows
      !
      !DIRECT=KK*NONSOLETOT*ECINFRC*EFS/(1+KK*NONSOLETOT*ECINFRC+K(1)
      !c    *ECINFR(1))
      !FFEFS=K(1)*ECINFR(1)*EFS/(1+KK*NONSOLETOT*ECINFRC+K(1)*ECINFR(1))
      !IF (T.LT.INCEPTDATE(2)) GOTO 2330
      DO V=1,B
      FFESR(V)=K(V)*ECINFR(V)*R(V)
```

```
      END DO
      DO V=1,B
      OPEFBK(V)=H(V)*ECINFR(V)*R(V)
      DEP(V)=L(V)*ECINFR(V)
      E(V)=G(V)*ECINFR(V)*R(V)
      NEWINFRENERGY(V)=CONSUMERFBK(V)-OPEFBK(V)-DEP(V)
      END DO
      NEWINFRTOT=0
      DO V=1,B
      NEWINFRTOT=NEWINFRTOT+NEWINFRENERGY(V)
      END DO
      !
      !Increment energy sector storages and energy market storage
      !
      !R(1)=EFS-DIRECT-FFEFS
      !IF (T.LT.INCEPTDATE(2)) GOTO 2505
      DO V=1,B
      R(V)=R(V)-FFESR(V)
      END DO
      !
      !This loop calculates the relative change in sector infrastructures
      !and updates them by adding the new infrastructures.
      !
      COMM=0
      DO V=1,B
      ECINFR(V)=ECINFR(V)+NEWINFRENERGY(V)
      CHANGE(V) = NEWINFRENERGY(V)/ECINFR(V)
      COMM=COMM+E(V)
      END DO
      !
      ! SUM IS THE SUM OF THE +VE ONLY VALUES OF NEWINFRENERGY(V)
      !
      SUM=0
      DO V=1,B
      NEWINFRENERGYO(V) = NEWINFRENERGY(V)
      IF (NEWINFRENERGYO(V).LE.0) NEWINFRENERGYO(V) = 0
      SUM = SUM + NEWINFRENERGYO(V)
      END DO
      NONSOLETOT=NONSOLETOT+COMM-COMMO
      PRINT 506,FLOAT(T),COMM,SUM
      PRINT 507,(NEWINFRENERGY(V),V=1,5)
      PRINT 507,(NONSOLARSHARE(V),V=1,5)
      PRINT 507,(ECINFR(V),V=1,5)
      PRINT 507,(E(V),V=1,5)
      PRINT 507,(DEP(V),V=1,5)
      PRINT 507,(ACCESS(V),V=1,5)
      PRINT 507,(QUOTA(V),V=1,5)
      PRINT 507,(R(V),V=1,5)
      PRINT 507,(TOTALSHARE(V),V=1,5)
      PRINT 507,(OPEFBK(V),V=1,5)
      PRINT 507,(CONSUMERFBK(V),V=1,5)
      PRINT 507,(FO(V),V=1,5)
      PRINT 507,FFESR(1),FFESR(2),FFESR(3),FFESR(4),FFESR(5)
      PRINT 507,(G(V),V=1,5)
      PRINT 507,(H(V),V=1,5)
      PRINT 507,(K(V),V=1,5)
      PRINT 507,(L(V),V=1,5)
      PRINT 507,GS,NEWINFRTOT,ECINFRC,NEWINFRCONSUMER,ACCESSAVERAGE
      PRINT 507,DEPC,DIRECT,OPCONSFBK,COMMO,NONSOLETOT
      PRINT 507,(CHANGE(V),V=1,5)
      FORMAT(E14.5,2E14.5)
      FORMAT(5E14.5)
      END DO
      END
```

_ELECVA$DUAO:[USER.HAYESD.ENERGY]A.LIS;595

(2) (1)
```
8000
224
10
8000
226
5
1000
1000
1
70
20
100
10000
100
1
1000
```

(1). Input parameters for 2 stock sectors [Energy 16].

(2) Input file read in.